2002 Annual Report

INTSORMIL

Sorghum/Millet International Research

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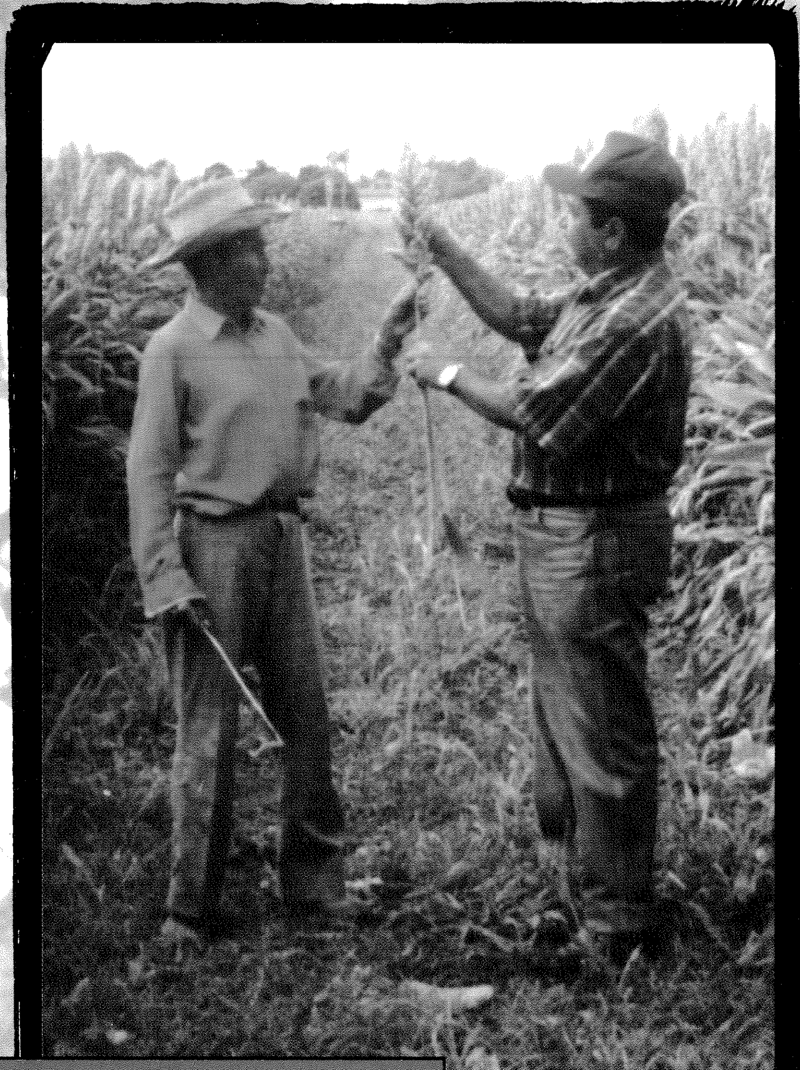
Sorghum/Millet Collaborative Research Support Program (CRSP)



Fighting Hunger and Poverty with Research
... a team effort

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René Clará (right) is the sorghum program coordinator and breeder for the Centro de Technologia de Agricola (CENTA) in El Salvador. He has conducted sorghum research for 30 years in Central America and has contributed significantly to the development of sorghum production and utilization. His work has contributed to sorghum improvement in countries throughout the region and the U.S. Ing. Clará is presently the INTSORMIL Regional Coordinator for Central America.

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Grain Sorghum/Pearl Millet Collaborative Research Support Program (CRSP)

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Introduction and Program Overview

The global community confronts an enormous task of stimulating economic growth in rural areas where 75% of the very poor (90% in Africa) currently live and ensuring the nutritional security of a world population that is growing in size and evolving in consumption patterns without intensifying environmental degradation, social security, or adverse consequences for human health. This challenge is not only great but it is also urgent. Today, access to food, sufficient, safe, and nutritious food, is the primary problem for nearly 800 million chronically undernourished people. Unless we act now, the next few decades will almost certainly find us unable to produce agricultural products sufficient to meet the demands of growing populations and changing diets. The majority of poor live in rural areas in developing countries and agricultural and food systems development is vital to economic growth; improving environmental quality; strengthening nutrition, health and child survival; improving the status of women; and promoting democratization.

Over the next 50 years, the global population will increase to 8-10 billion, requiring advances in scientific knowledge across a broad range of agricultural endeavors, i.e., developing more productive food and commodity cultivars, improving nutritional quality of crop and livestock products, reducing food and commodity yield losses due to pests and diseases, ensuring healthy livestock, developing sustainable and responsible fisheries and aquaculture practices, optimizing the use of forests, managing water more efficiently, protecting and improving land productivity, and conserving and managing genetic diversity.

According to an issues paper on an international assessment on agricultural science and technology in reducing hunger and improving rural development, which is being conducted by the World Bank, meeting these demands will require productivity increases and product diversification to improve the livelihoods of the poor, to protect the environment in both developed and developing countries that is grounded in equity, that addresses key issues such as trade, Intellectual Property Rights (IPR), and land tenure, and that enhances agricultural productivity while encouraging the sustainable use of natural resources.

According to Entering the 21st Century – World Development Report 1999-2000, about 900 million people in almost 100 countries are affected by drought and desertification, and by 2025, that number will double. The population of the world has doubled since 1940, but fresh water use has increased fourfold. Water scarcity is becoming more widespread, with concomitant effects on regional peace and global food security. Nearly all of the three billion increase in global population which is expected by 2025 will be in developing countries where water is already scarce. To meet the increasing demand for food in those countries, there is an increasing demand for more efficient production and new ways of utilizing drought-tolerant crops which have a competitive advantage to produce food under conditions of unpredictable and scarce rainfall. According to Dr. Jeff Dahlberg, Seed World, June 2001, water scarcity will require a blue revolution, a revolution that involves turning over acreage currently planted to crops which require heavy irrigation to drought tolerant grains such as sorghum and pearl millet. Dr. Dahlberg states that the blue revolution will be the next major change in agricultural production, and its impact could be as great, if not greater, than that of the Green Revolution.

In developing countries of the semi-arid regions, sorghum and millet, two important cereal grains, make the difference between food security and famine. In the United States, sorghum is important to the balance of trade, is an important feed in the production of beef, and is increasingly in demand as a raw material for food and as a renewable feedstock for production of fuel. In 2001, 58.5 Tg (million tons) of sorghum were produced worldwide, of which 18.4 Tg were produced in sub-Saharan Africa, mainly for direct consumption by humans, and 13.1 Tg were produced in the United States, mainly for livestock feed to produce meat for human consumption. In 2000, the United States exported 6.6 Tg of grain sorghum mainly for livestock feed, and in 1999, U.S. grain sorghum exports were worth $626 million. Large areas are planted to sorghum each year. For example, in 2001 sorghum was produced on 42.6 million hectares (ha, or 166,406 square miles, [sq mi]) worldwide, 22.2 million ha (86,752 sq mi) in Africa, and 3.473 million ha (13,566 sq mi) in the United States. About 500 million people worldwide depend upon sorghum for food, and most of these people are in developing countries where droughts and famine are common occurrences. Clearly, sorghum production and utilization as food and feed are vitally important to developing countries and to the United States.

Millets, which include several types such as pearl millet, finger millet, and proso millet, are cereal crops even better adapted to arid ecosystems than is sorghum, and pearl millet is a staple for 300 million people worldwide. Most of these people are in countries within semi-arid regions where malnourishment is a persistent problem. In 2001, 37.4 million hectares (146,101 sq mi) of millets were harvested worldwide, of which 20.3 million ha (79,361 sq mi) were harvested in sub-Saharan Africa, and 234,720 ha (916.8 sq mi) were harvested in the United States. In 2001, the amount of millets harvested worldwide was 29.2 Tg, of which 13.8 Tg were harvested in sub-Saharan Africa and 436.580 Mg (thousand tons) were harvested in the United States. Millets are crops used mainly for direct consumption by humans in developing countries, and the millets are used mainly for feeding livestock, particularly poultry, in developed countries. Pearl millet is an important cereal crop which provides food energy and other nutrients to hundreds of millions of people in areas which currently suffer from malnutrition, particularly Africa and southern Asia. The United States and all other participants in the World Food Conference have a stake in promoting the production and utilization of sorghum and pearl millet to help end hunger, particularly in Africa.

In October 1999, the International Food Policy Research Institute (IFPRI) noted that in both developed and developing countries, the rate of increase in cereal yields is slowing from the days of the Green Revolution, partly due to reduced use of inputs like fertilizer and partly due to low levels of investment in agricultural research and technology. In World Food Prospects: Critical Isssues for the Early Twenty-First Century, IFPRI points out that "without substantial and sustained additional investment in agricultural research and associated factors, it will become more and more difficult to maintain, let alone increase, cereal yields in the longer term. The gap in average cereal yields between the developed and developing countries is slowly beginning to narrow, but it is widening considerably within the developing world as Sub-Saharan Africa lags further and further behind the other regions . . . ." In its 2020 Global Food Outlook Report, IFPRI observes that "Cultivating more and more land will not solve Sub-Saharan Africa's food security problems for the long-term. Between 1967 and 1997, the region expanded cereal cultivation by 31 million hectares and roots and tubers cultivation by 8 million hectares. This rate of expansion is not sustainable; therefore, higher crop yields are needed to reduce malnutrition in Africa."

Agricultural research provides benefits not only to producers of agricultural products but also to processors and consumers of agricultural products. Agricultural research has proven itself continuously as providing improvements which yield products of greater quantity and quality, as well as improved health to consumers and broad-based economic growth which goes beyond producers and consumers. In the U.S. Action Plan on Food Security – Solutions to Hunger, published in March 1999, the United States government states that one of the ways that the United States plans to contribute to the global effort to reduce hunger is by the United States' continuing commitment to support international agricultural research through the Collaborative Research Support Programs.

The Collaborative Research Support Program (CRSP) concept was created by the U.S. Agency for International Development (USAID) and the Board for International Food and Agriculture Development (BIFAD), under the auspices of Title XII of the Foreign Assistance Act, as a long term mechanism for mobilizing the U.S. Land Grant Universities in the international food and agricultural research mandate of the U.S. Government. As amended in 2000, Title XII assures a wider inclusion of organizations by including land grant universities, other universities, and their public and private partners in the U.S. and other countries. The CRSPs are communities of U.S. Land Grant Universities and other universities working with USAID and other U.S. Federal Agencies, strengthening and enhancing National Agricultural Research Systems (NARS), collaborating country colleges and universities. The CRSPs also work closely with the International Agricultural Research Centers (IARCs), private agencies, industry, and private voluntary organizations (PVOs) fulfilling their mandate. The Sorghum and Millet Collaborative Research Support Program is one of nine CRSPs currently in operation.

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production and utilization for the mutual benefit of the U.S. and Less Developed Countries (LDCs). Collaborating scientists in the NARS of developing countries and the U.S. jointly plan and execute research that mutually benefits all participating countries, including the United States.

INTSORMIL takes a regional approach to sorghum and millet research in western, southern, and eastern Africa, and in Central America. INTSORMIL focuses resources on prime sites in the four regions supporting the general goals of building NARS institutional capabilities, creating human and technological capital to solve problems constraining sorghum and millet production and utilization. INTSORMIL's activities are aimed at achieving sustainable, global impact, promoting economic growth, enhancing food security, and encouraging entrepreneurial activities. The six universities currently active in the INTSORMIL CRSP are Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University. In addition, scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia participate in INTSORMIL. What were formerly referred to as "host" countries are now referred to as "collaborating" countries to indicate the closer and more collaborative relationships that have developed between the United States and those countries as a result of all that has been accomplished during the past twenty-three years of the INTSORMIL CRSP.

Because sorghum and millet are important food crops in moisture-stressed regions of the world, they are staple crops for millions in Africa and Asia, and, in their area of adaptation, sorghum and millet have a distinctly competitive advantage to yield more grain than other cereals. As wheat and rice products have been introduced to urban populations in developing countries, traditional types of sorghum, because of some quality characteristics, have not been able to effectively compete with wheat and rice products. However, as a result of research by INTSORMIL researchers and others, improved, food-quality sorghums produce grain that can be used for special ethnic and dietary products as well as for traditional food products. Special white sorghums developed by INTSORMIL collaborative research in Mali have improved characteristics which allow preparation of high-value food products made of as much as 100% sorghum which can compete successfully with wheat and rice products in village and urban markets. Couscous made from food-quality, hybrid sorghum is being market tested in Niger. The development of both open-pollinated and hybrid sorghums for food and feed with improved properties such as increased digestibility and reduced tannin content has contributed to sorghum becoming a major feed grain in the U.S. and in South America. Pearl millet is also becoming an important feed source in poultry feeds in the southeastern United States. Improved varieties and hybrids of pearl millet, like improved lines of sorghum, can be grown in developing countries, as well as the United States, and have great potential for being processed into high-value food products which can be sold in villages and urban markets, thus competing successfully with imported wheat and rice products. These developments are results of the training and collaborative, international scientific research that INTSORMIL has supported both in the United States and collaborating countries.

Although significant advances have been made in improvement and production of sorghum and millet in the regions of developing countries which INTSORMIL serves, population growth rates continue to exceed rates of increase of cereal production capacity. There remains an urgent need to continue the momentum of our successes in crop improvement, improved processing of sorghum and millet, and strengthening the capabilities of NARS scientists to do research on constraints to production and utilization of sorghum and millet.

INTSORMIL maintains a flexible approach to accomplishing its mission. The success of the INTSORMIL program can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities.

- ***Developing institutional and human capital***: INTSORMIL provides needed support for education of agricultural scientists in both developing countries and the United States. The results of this support include strengthening the capabilities of institutions to do research on sorghum and millet, development of collaborative research networks, promoting and linking to technology transfer and dissemination of technologies developed by research, and enhancing national, regional, and global communication linkages. A major innovative aspect of the INTSORMIL focus is to maintain continuing relationships with scientists of collaborating countries upon return to their research posts in their countries. They become members of research teams of INTSORMIL and NARS scientists who conduct research on applications of existing technology and development of new technology. This integrated relationship prepares them for leadership roles in their national agricultural research systems and regional networks in which they collaborate. From the strategic standpoint, the education of agricultural scientists of developing-country scientists by INTSORMIL contributes to the economic and political stability of developing countries, through cultural ties and long-term scientific collaboration, helping enable the collaborating countries to achieve economic growth necessary to becoming more significant trading partners with their neighbors and the United States. Strategically for the United States, it is crucial to maintain a cadre of both scientists knowledgeable about sorghum and millet within and outside the United States to assure the safety and growth of these two crops in the United States, since both crops are native to Africa.

- ***Conserving biodiversity and natural resources***: Research results of the collaborative research teams include development and release of enhanced germplasm, development and improvement of sustainable production systems, development of sustainable technologies to conserve biodiversity and natural resources and to enhance society's quality of life and to enlarge the range of agricultural and environmental choices. Thus, INTSORMIL promotes conserving millet and sorghum germplasm, conserving natural control of arthropod pests and diseases of sorghum and millet, developing resource-efficient cropping systems, developing integrated pest management programs, developing cultivars with improved nutrient and water use efficiencies, and evaluating impacts of sorghum/millet technologies on natural resources and biodiversity.

- ***Developing research systems***: Collaboration in the regional sites in countries other than the United States has been strengthened by using U.S. and NARS multi-disciplinary research teams focused on unified plans to achieve common objectives. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and pearl millet. The outputs from these disciplinary areas of research are linked to immediate results. INTSORMIL uses both traditional science of proven value and newer disciplines such as molecular biology in an integrated approach to provide products of research with economic potential. These research products which alleviate constraints to production and utilization of sorghum and pearl millet are key elements in fighting hunger and poverty by providing means for economic growth and improved health. New technologies developed by INTSORMIL collaborative research are extended to farmers' fields in developing countries and the United States through partnerships with NGOs, research networks, extension services and the private sector. In addition, economic analysis by INTSORMIL researchers plays a crucial role by enabling economic policymakers to more intelligently consider policy options to help increase the benefits and competitiveness of sorghum and pearl millet as basic food staples and as components of value-added products.

- ***Supporting information networking***: INTSORMIL research emphasizes working with both national agricultural research systems and existing sorghum and millet networks to promote effective technology transfer from research sites within the region to local and regional institutions. Technology transfer is strengthened by continued links with regional networks, International Agricultural Research Centers, and local and regional institutions. Emphasis is placed on strong linkages with extension services, agricultural production schemes, private and public seed programs, agricultural product supply businesses, and nonprofit voluntary organizations, such as NGOs and PVOs, for efficient transfer of INTSORMIL-generated technologies. Each linkage is vital to development, transfer, and adoption of new production and utilization technologies, with the ultimate goal being economic and physical well-being to those involved in production and utilization of these two important cereals.

- ***Promoting demand-driven processes***: INTSORMIL economic analyses focus on prioritization of research, farm-level industry evaluation, development of sustainable food technology, processing and marketing systems, are all driven by the need for stable markets for the LDC farmer. INTSORMIL seeks alternate food uses and new processing technologies to save labor and time required in preparation of sorghum millet for food. Research products transferred to the farm will seek to spur rural economic growth and provide direct economic benefits to consumers. INTSORMIL assesses consumption shifts and socioeconomic policies to reduce effects of price collapses, and does research to improve processing to yield products of sorghum and millet which are attractive and useful to the consumer. Research by INTSORMIL agricultural economists and food scientists seeks to reduce effects of price collapse in high yield years, and to create new income opportunities. INTSORMIL socioeconomic projects measure impact and diffusion and evaluate constraints to rapid distribution and adoption of introduced new technologies.

The INTSORMIL program addresses the continuing need for agricultural production technology development for the developing world, especially in the semi-arid tropics. There is international recognition by the world donor community that national agricultural research systems (NARS) in developing countries must assume ownership of their development problems and move toward achieving resolution of them. The INTSORMIL program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits back to the U.S. agricultural sector. These aspects of INTSORMIL present a win-win situation for international agricultural development, strengthening developing countries' abilities to solve their problems in the agricultural sector while providing benefits to the United States.

Administration and Management

The University of Nebraska (UNL) is the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID. UNL subgrants are made to the participating U.S. Universities and USDA/ARS for the research projects between U.S. scientists and their collaborating country counterparts. A portion of the project funds, managed by the ME and U.S. participating institutions, support regional research activities. The Board of Directors (BOD) of the CRSP serves as the top management/policy body for the CRSP. The Technical Committee (TC), External Evaluation Panel (EEP) and USAID personnel advise and guide the ME and the Board in areas of policy, technical aspects, collaborating country coordination, budget management, and review.

Several major decisions, events and accomplishments of INTSORMIL during the past year occurred in the United States and collaborating countries.

The 2001-2002 Technical Committee was elected. Its members are:

- Dr. Gary Peterson, Chair, Texas A&M University (Southern Africa Regional Program Coordinator)
- Dr. John Sanders, Vice Chair, Purdue University (Agronomy/Physiology)
- Dr. Henry Pitre, Secretary, Mississippi State University (Plant Protection)
- Dr. Bruce Hamaker, Purdue University (Economics/Utilization)
- Dr. Gebisa Ejeta, Purdue University (Horn of Africa Regional Program Coordinator)
- Dr. Wayne Hanna, Breeding
- Dr. Stephen Mason, University of Nebraska (Central America Regional Coordinator)
- Dr. Aboubacar Touré, Institut de Economie Rurale, [Regional (Mali) Coordinator]
- Dr. Peter Esele [Regional (Uganda) Coordinator].

- Ten Mozambican agricultural scientists funded by USAID/Mozambique arrived in July, 2001. Eight of the participants were not adequately competent in English, and so remedial work in the United States was needed to enable them to adequately understand written and spoken

English and articulately express themselves with both written and spoken English. As of September 2002 seven have completed intensive English training and nine have been placed in programs of study for a graduate degree at a CRSP university in the United States with the assistance of the INTSORMIL CRSP Management Entity. One is completing the intensive english language program.

- INTSORMIL was well represented at the meeting of the Global Consortium of Higher Education and Research for Agriculture (GCHERA), July 12-14, 2001 in San Francisco, CA. Dr. David Sammons, Purdue University and INTSORMIL Board of Directors was a key organizer of the conference which hosted representatives of institutions of higher education and research from approximately 140 different countries. Dr. Aberra Debelo and Dr. Aberra Deressa represented the Ethiopian Agricultural Research Organization (EARO). Dr. Hamis Saadan, represented the Ministry of Agriculture and Food Security of Tanzania. Dr. Thomas Crawford, Associate Director of INTSORMIL presented a poster paper on behalf of the CRSP programs.

- The Program Director and the Associate Program Director represented INTSORMIL at the meeting of the CRSP Council Steering Committee, Kona, Hawaii County, Hawaii. November 12-13, 2001

- INTSORMIL initiated two new disciplinary projects with West Texas A&M University and the University of Nebraska and one multi disciplinary project with Kansas State University which includes Kansas State University and Texas A&M University. The disciplinary projects were Sustainable Management of Insect Pests, Dr. Bonnie Pendleton, P.I. and Soil and Water Management for Improving Sorghum Production in Eastern Africa, Drs. Charles Wortman and Martha Mamo, PIs. The multi disciplinary team project is "Enhancing the utilization of grain sorghum and pearl millet through the improvement of grain quality via genetic and nutrition research, Drs. Mitchell Tuinstra, Joe Hancock, Kansas State University and William Rooney and Clint Magill, Texas A&M University.

- Dr. Wayne Hanna,USDA/ARS/Tifton, GA and Principal Investigator for the INTSORMIL "Breeding Pearl Millet with Improved Performance, Stability and Resistance to Pests" project retired July 1, 2002. INTSORMIL re-advertised the project and Dr. Jeff Wilson, USDA/ARS/Tifton, GA wrote the successful proposal for continuing this project. The new project started July 1, 2002.

- INTSORMIL contributed to an exhibit on the nine CRSPs presented at the Fourth Annual Agricultural Research and Education Exhibition and Capitol Hill Reception in Washington, D.C., March 5, 2002. The Program Director and Associate Program Director represented INTSORMIL.

- The major publications organized and published by the ME office @during the year included:

  - INTSORMIL 2001 Annual Report, INTSORMIL Publication 01 - 5.

  - INTSORMIL 2000 Annual Report Executive Summary, INTSORMIL Publication 02 - 01.

  - West African Hybrid Sorghum and Millet Seed Workshop, INTSORMIL Publication 02 - 02.

  - "Inside INTSORMIL" Newsletter, March 2002, INTSORMIL Publication 02 -03.

  - INTSORMIL Directory, Publication 02 - 04, September 2002.

Education

Within INTSORMIL's regions of collaborative research and the United States, education of collaborating scientists contributes to the capability of each collaborating country research program to stay abreast of economic and ecological changes which alter the balance of sustainable production systems. The strengthening of collaborating country research institutions contributes to their capability to predict and be prepared to meet the challenges of economic and ecological changes which affect production and utilization of sorghum and millet. A well balanced agricultural research institution must prioritize and blend its operational efforts to conserve and efficiently utilize its natural resources while meeting economic needs of the population in general and the nutritional needs of both humans and livestock. To this end, education is an extremely valuable component of development assistance.

Year 23 Education (July 1, 2000 - June 30, 2001)

During Year 23, 2001-2002, there were 35 students from 16 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 51% of these students came from countries other than the U.S.. The number of students receiving 100% funding by INTSORMIL in 2001-2002 totaled 10. An additional 23 students received partial funding from INTSORMIL. Two students were funded under the Mozambique Inter-CRSP project.

Conferences and workshops are an important means of continuing education for scientists doing research on sorghum and millet. Participation in conferences and workshops increases the sharing of information, a key factor in making more efficient research strategies and more efficiently carrying out research. During Year 23, INTSORMIL supported the Sorghum Pests and Diseases Workshop in Managua, Nicaragua, June 10-14, 2002. Forty participants attended the workshop at which they learned about Central America regional state-of-the-art research on diseases of sorghum and pearl millet. One individual participated in the Parasitic Weed Symposium in France; one person attended the American Seed Trade Meetings in Chicago, Ill; . In addition, a number of scientific writing workshops were offered by an INTSORMIL PI in South Africa, India, and Australia. About 328 individuals improved their scientific writing skills by participating in these workshops. Of the participants at these conferences and workshop INTSORMIL sponsored 174 women and 215 men for a total of 389.

Another important category of education which INTSORMIL supports is non-degree research activities, namely post-doctoral research and research of visiting scientists with INTSORMIL PIs in the United States. During Year 23, eighteen scientists improved their education as either post-doctoral scientists (5) or visiting scientists (13). Their research activities were in the disciplines of plant breeding, agronomy, food quality/utilization, plant pathology, poultry nutrition and Striga physiology. These scientists came to the United States as post-doctoral scientists or visiting scientists from Brazil, El Salvador, France, Ghana, Mali, Nicaragua, Niger, Zambia, Namibia and the United States.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as newsletters, publications, the exchange of scientists, and the exchange of germplasm. The INTSORMIL Global Plan is designed for research coordination and networking within ecogeographic zones and where relevant between zones. The Global Plan:

- Promotes networking with IARCs, NGO/PVOs, Regional networks (ROCAFREMI, ROCARS, ASARECA, SADC/SMINET, SADC/SMIP and others), private industry and government extension programs to coordinate research and technology transfer efforts.

- Supports INTSORMIL participation in regional research networks to promote professional activities of NARS scientists, to facilitate regional research activities (such as multi-location testing of breeding materials), promote germplasm and information exchange, and facilitate impact evaluation of new technologies.

- Develops regional research network, short-term and degree training plans for sorghum and pearl millet scientists.

Over the years, established networking activities have been maintained with ICRISAT in India, Mali, Niger, Central America and Zimbabwe; SAFGRAD, WCASRN (ROCARS), WCAMRN (ROCAFREMI), ASARECA, ECARSAM and SMIP/SMINET in Africa; CLAIS and CIAT of Central and South America and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditures of research dollars. There also has been efficient collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training. INTSORMIL currently cooperates with the ICRISAT programs in East, Southern, and West Africa, with WCASRN and WCAMRN in West/Central Africa and with SMIP/SMINET in Southern Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with the WCAMRN in West Africa has much potential in allowing INTSORMIL utilization scientists to collaborate regionally. ROCAFREMI is a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last four years, INTSORMIL, the Bean/Cowpea CRSP, and World Vision International have been working with NARS researchers and farmers in five countries under the West Africa Natural Resource Management Project, creating and using a technology-transfer network in West Africa. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Regional Activities and Benefits

West Africa (Niger, Burkina Faso, Nigeria)

In the Niger sorghum hybrid project, new prospective hybrids were tested and some promising lines were identified. A new generation of hybrids, with an improved A line and tan plant color are desired for the hybrid program. Female parents TX623A and 223A were each increased at Lossa station. NAD-1 and F1-223 hybrids were produced at the Tillabery station. With assistance from networking partners, on-farm seed production trials continue and progress has been made in training and production issues.

The couscous and high-quality flour processing unit in Niamey has had continued success in the past year with completion of a large market test of products, additional activities financed through ROCARS, and initiation of entrepreneurial activities.

Progress has been made on sorghum midge control through identification of resistant lines in Niger. New collaboration with the new INTSORMIL PI, Dr. Bonnie Pendleton brings new input into the entomology program.

Micro-dose fertilizer studies show the advantage of small additions of fertilizer during cropping. Economic studies show that farmers are investing in fertilizer and are gaining economic benefit.

New INTSORMIL projects in Nigeria, two focused on millet hybrids and processing, and one on sorghum trials have shown strong contributions to the program. Further links with U.S. collaborators and addition of more PIs in Burkina Faso will also strengthen the regional effort.

West Africa (Mali, Senegal, Ghana)

Generally, the activities in the Western Region of West Africa proceeded well in 2001 in spite of adverse weather conditions in several areas, and some interruptions in travel plans. A strong positive output has been realized from the first full year of INTSORMIL collaborative activities in Ghana and Senegal with activity in breeding, pathology, entomology, agronomy, and *Striga*. The strong Mali research program in IER continues to show leadership in the region, organizing and hosting a West Africa Workshop on Biotechnology, and is procuring, packaging, and distributing seed of several West African nurseries and tests which serve as a means of enhancing germplasm exchange, scientist to scientist cooperation, and collaborative research activities among scientists in several West African countries.

One concern is regarding the best way to organize, coordinate, etc., research activities among the various countries in West Africa. Adding the countries of Ghana, Senegal, Burkina Faso, and Nigeria strengthens the research effort across the region, but the limited funds for these new countries is a problem. Furthermore, there are other PIs in the new countries with interest in becoming collaborators as well as the case of ITA in Food Technology in Senegal which is pursuing a MOU with INTSORMIL. Also, the demands on U.S. PIs in needed travel, etc., is a concern both because of time constraints and money resources. Also, the reduced number of PIs with active collaboration and travel in the area has been a problem. The addition of the new projects and PIs is positive and should help in the future. Positive moves in that area include John Leslie's travel and efforts on behalf of pathology, pathology needs assistance beyond grain toxin studies. The recent addition of Jeff Wilson as a new PI hopefully will contribute in the pathology area, as well as possibly Clint Magill. Bonnie Pendleton has already shown a strong effort in strengthening collaboration in entomology. There is still somewhat of a deficiency in the food technology and sorghum agronomy area. The PI Conference in Ethiopia in late 2002 will serve as a forum where all Host Country and U.S. PIs can develop a better coordinated effort in all of West Africa.

There continues to be a need in the analysis and promotion regarding contract production, marketing, and identity preserved (IP) issues, and use of the tan-plant variety, N'Tenimissa. Hopefully, some short-term help can be identified to fill this need for technical assistance. The very promising activity completed in the 2001 season by a local entrepreneur with assistance from the IER and ROCARS needs to be supported, analyzed, and continued in every possible way.

The project has made some major achievements in all four of the major objectives during this reporting period. The contract production of over 11 tons of N'Tenimissa grains with about 50 farmers in four villages in 2001 and the movement of this identity preserved (IP) grain through the marketing channels certainly is a promising activity in promoting economic growth and moving sorghum to a value-added crop. The sale of 1 kilo bags of N'Tenimissa sorghum flour (Sorgha Phar), the Deli-ken cookies, and the new effort on marketing a sorghum syrup and a non-alcohol sorghum beverage all promote economic growth and improve overall nutrition. The new sorghum breeding cultivars, such as "Uassa", and others in on-farm trials and in the advanced stage of the breeding pipeline offer potential to increase yields and improve quality and value of grain as a cash crop. Agronomic research helps exploit the genetic potential of new and existing cultivars. The development of hybrids in the future certainly would be a big step in improving yields.

The current people in training will strengthen the institutional capacity in Mali. New future training opportunities in Mali, and hopefully with Ghana and Senegal, will materialize to strengthen institutional capacity in those countries.

Horn of Africa (Ethiopia, Eritrea, Kenya, Uganda)

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya and Uganda; the results from each of these studies is documented in this report. Host country PIs in each country have taken keen interest in collaborating with US PIs where partnerships have been developed. Because of expanded collaborative involvement in several countries, more US PIs are needed to provide collaborative linkages with host country scientists. New PIs joining INTSORMIL are expected to take advantage of the opportunities for collaboration in the Horn of Africa region, where host country scientists and programs continue to appreciate and welcome technical support provided by INTSORMIL.

Sorghum breeding efforts in Ethiopia have particularly gone well. Work on development and evaluation of experimental sorghum hybrids have resulted in identification of elite hybrids with potential for wide cultivation in the lowland areas of the country. Efforts on *Striga* control have fosused on regional testing of an integrated package of technologies that included tied-ridging as a water conservation measure, nitrogen fertilization, and resistant sorghum cultivars. This activity is managed and implemented as a pilot project with supplemental funding from the Office of Foreign Disaster Assistance (ODA) of the USAID.

In Year 23, under the auspices of IGAD with funds provided by USAID/REDSO/East Africa, a major study assessing the state of dryland research in the Horn of Africa region was completed under the leadership of Dr. John Sanders and in cooperation with a number of agricultural scientists from the Horn of Africa.

The survey provides extensive documentation regarding dryland agriculture in the region, technologies available, and research gaps that can be addressed through future research. A stakeholders' workshop was held in Nairobi, Kenya October 30-November 2, 2001 to discuss the results of this study and to develop a dryland research agenda for the Horn of Africa.

Southern Africa (Zambia, South Africa, Namibia, Botswana, Mozambique and SIMNET/SMIP, Bulawayo, Zimbabwe)

Most activities were carried out as plannedfor the Southern Africa Region. However, research is on-going and depending on the program, continues to make progress toward objectives, and has produced results that are important to increasing the production and quality of end-products of sorghum and pearl millet in the Southern Africa region.

Hybrid parents have been bred for sorghum and are nearing completion for pearl millet. A large amount of sorghum breeding material and varieties in use have been characterized for resistance to major diseases and sugarcane aphid. Multi-location testing of sets of such lines provides strategic geographic information on distribution and severity of diseases. Factors influencing the incidence and control of sorghum ergot are now better understood, leading to better control of the disease, especially in hybrid production fields. Food quality research can lead to increased use of sorghum in various products. Linking variety qualities to specific end uses is shown to be very important.

Active collaboration exists in sorghum breeding, plant pathology, grain quality, and marketing. Collaboration in entomology has been re-established. Regional pearl millet breeders continue interaction with INTSORMIL at a reduced level due to both retirements in the region and in INTSORMIL. Efforts are on-going to continually refocus activity for increased relevance and generation of useful technology. Collaboration can be improved and increased in all research areas. Additional collaboration is needed in all disciplines for all research objectives. Unfortunately, there are more collaborators and opportunities in Southern Africa than there are INTSORMIL principal investigators.

Central America

Since 1999 the Central America program has increased activity in El Salvador and Nicaragua. The research activities developed for 2000 - 2001 were successfully completed, and administrative procedures for reporting research results and financial expenditures were developed. A conference was held to report research results and plan collaborative research priorities for 2002 - 2006. Communication and coordination of the many groups involved in the program remains a challenge. Graduate education of scientists in national programs is needed, but identification of candidates who are proficient in English with firm commitments to work in national programs is difficult, and funding is limited. On the whole, given the short time in the present collaborative model in Central America, the program is functioning well due to the commitment of scientists in the region and has resulted in selection of improved cultivars, management strategies for fall armyworm and sorghum midge, identified priority disease problems, developed sorghum flour substitution technology, and implemented research on nitrogen rates and nitrogen use efficiency of sorghum germplasm adapted to the region.

Regional Benefits by Technical Thrust

INTSORMIL provides a wide range of documented benefits to collaborating countries, U.S. agriculture, and the broader scientific community. Many of these benefits have reached fruition with greater economic benefits to producers and consumers, improved sorghum and millet research programs, and improvement of the environment. Others are at intermediate stages (“in the pipeline”) that do not allow quantitative measurement of the benefits at present, but do merit identification of potential benefits in the future. The collaborative nature of INTSORMIL programs has built positive long-term relationships between scientists, citizens and governments of collaborating countries and the United States. This has enhanced university educational programs and promoted understanding of different cultures enriching the lives of those involved, and hopefully making a small contribution to world peace, in addition to improving sustainable sorghum and pearl millet production in developing countries and in the United States.

Germplasm Enhancement and Conservation

Producing improved seed that seed companies and farmers can use, INTSORMIL researchers in developing countries and the United States have collaborated to develop improved, high yielding varieties and hybrids. Progeny were identified that combine several needed favorable traits into a single genotype. Advanced selections are being evaluated using on-farm trials to measure performance. As research continues to generate new technology, the importance of testing on-farm, and soliciting producer input on research activities will increase. Technology–in this case, improved germplasm–developed by INTSORMIL has been adopted by private industry and used in hybrid production and breeding programs. Impact assessment studies have consistently shown a high rate of return on investment from research conducted by this project.

Breeding sorghum varieties and hybrids for use in developing countries and the United States requires proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Germplasm exchange, movement of seeds in both directions between the United States and collaborating countries, involves populations, cultivars, and breeding lines which carry resistance to insects, diseases, the parasitic weed, *Striga*, drought, and which are tolerant to edaphic stresses, one of which is soil acidity. Research and germplasm development activities in

INTSORMIL attempt to address these essential requirements.

INTSORMIL/Purdue project (PRF-207) addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in some of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed. Training of NARS scientists is an important component of our research and development effort. Several years ago INTSORMIL project PRF-207 spearheaded an initiative that brought together several organizations, the USDA, ICRISAT, ARC/Sudan with INTSORMIL, in assembling the Sudan sorghum collections from around the world for organized evaluation and cultivation. The collection was successfully grown, characterized, catalogued, and placed in permanent storage for the benefit of mankind. In this report, they describe the results of an analysis of genetic diversity conducted on the Sudan collection by Cecile Grenier this last year. The study co-authored by all involved in the characterization of the germplasm has been submitted for consideration of publication in an international journal.

INTSORMIL plant breeders also develop elite materials with high yield potential which can be used as cultivars per se or used as parents in breeding programs. Specific germplasm releases (including breeding lines) for collaborating country use include the following.

- Improved yield (for all collaborating countries)
- Improved drought tolerance (Africa and drier areas of Latin America)
- Acid soil tolerance
- *Striga* resistance (West, Eastern Africa, and Southern Africa)
- Midge and greenbug resistance (Latin America)
- Downy mildew resistance (Latin America and Botswana)
- Anthracnose resistance (Latin America and Mali)
- Charcoal rot and lodging resistance (Africa and drier areas of Latin America)
- Head smut and virus resistance (Latin America)
- Foliar disease resistance (for all collaborating countries)
- Improved grain quality characteristics for food and industrial uses (for all collaborating countries)

Generally, the activities in the Western Region of West Africa under the guidance of TAM-222 proceeded well in 2001 in spite of adverse weather conditions in several areas, and some interruptions in travel plans. There has been a strong positive response to the first full year of INTSORMIL collaborative activities in Ghana and Senegal with activities in breeding, pathology, entomology, agronomy, and *Striga* research. The strong Mali research program in IER continues to show leadership in the region, organizing and hosting a West Africa Workshop on Biotechnology, and in the procuring, packaging, and distributing seed of several West African nurseries and tests which serve as a means of enhancing germplasm exchange, scientist to scientist cooperation, and collaborative research activities among scientists in several West African countries.

One concern is regarding the best way to organize, coordinate, etc., research activities among the various countries in West Africa. Adding the countries of Ghana, Senegal, Burkina Faso, and Nigeria strengthens the research effort across the region, but the limited funds for these new countries is a problem. Furthermore, there are other PIs in the new countries with interest in becoming collaborators as well as the case of ITA in Food Technology in Senegal where they are pursuing a MOU with INTSORMIL in case some additional funds become available in the future. Also, the demands on U.S. PIs in needed travel, etc. is a concern of both availability of time and available resources. The reduced number of U.S. PIs with active collaboration and travel in the area has been a problem. The recent addition of the new projects and PIs is positive and should help in the future. Positive moves in that area include Dr. John Leslie's travel and efforts on behalf of sorghum pathology. There are still pathology assistance needs which go beyond grain toxin studies. The recent addition of Dr. Jeff Wilson as a new PI, hopefully, will contribute in the pathology area, as well as possibly that of Dr. Clint Magill. Dr. Bonnie Pendleton has already shown a strong effort in strengthening collaboration in entomology. There is still somewhat of a deficiency in the food technology and in the sorghum agronomy area. Hopefully, the PI Conference in Ethiopia in late 2002 will serve as a forum where all Host Country and U.S. PIs can develop a better coordinated effort in all of West Africa.

The very promising activity done in the 2001 season by a local entrepreneur with assistance from the IER and ROCARS needs to be supported, analyzed, and continued in every possible way.

TAM-222 project has made some major achievements in all the four major strategic objectives during this reporting period. The contract production of over 11 tons of N'Tenimissa grains with about 50 farmers in four villages in 2001 and the movement of this identity preserved (IP) grain through the marketing channels certainly is a promising activity in promoting economic growth and moving sorghum to a value-added crop. The sale of 1 kilo bags of N'Tenimissa sorghum flour (Sorgha Phar), the Deli-ken cookies, and the new effort on marketing a sorghum syrup and a non-alcohol sorghum beverage all promote economic growth and improve overall nutrition. The new sorghum breeding cultivars, such as "Uassa", and others in on-farm trials and in the advanced stage of the breeding pipeline offer potential to increase yields and improve quality and value of grain as a cash crop. Agronomic research helps exploit the genetic potential of new and existing cultivars. The development of hybrids in the future certainly would be a big step in improving yields.

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Under TAM-223 progress was made in all research areas. Germplasm was obtained and evaluated for resistance to economically important insect pests. Selections were made to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield and widely adapted hybrids. Results from previous molecular mapping studies are used in a marker-assisted selection program for greenbug resistance and stay green.

Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. As research continues to generate new technology, the importance of testing on-farm and soliciting producer input on research activities will increase.

During the life of TAM-223 significant research progress has been achieved. Technology (germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Collaboration with research programs in Nicaragua, El Salvador, and Southern Africa (South Africa, Botswana, Zambia, and Mozambique) has significantly increased TAM-223 activity. Impact assessment studies show a high rate of return on investment from research conducted by this project.

In pearl millet breeding, the INTSORMIL ARS-204 project has found that the stability of grain yield of pearl millet across cycles for the population hybrids was encouraging. The failure of the population hybrids to out-yield the local checks was disappointing, but provided important information on the need to more precisely select the parental combinations to match morphological characteristics and local adaptability. The identification of SOSAT-C88 as a good general combiner is significant. The principal investigator doing pearl millet breeding in Georgia, having decided to maximize impact by having visiting scientists spend time with him during the pollinating season, reported that the visit from Moussa Sanogo, pearl millet breeder from Mali to Tifton, GA resulted in a publication in the International Sorghum and Millets Newsletter. The visit by Ferdinand Muuka, pearl millet breeder from Zambia will result in another short manuscript on pollen storage. High coefficients of variation (CVs) for the data from collaborating sites is due to numerous factors, including bird damage, are a concern.

The ARS-204 project is continuing to test the population hybrids in Nigeria, Senegal, and Georgia in 2002 (and possibly in Zambia). This will give them at least two years of data from each location where they have been tested.

Sustainable Production Systems

In the project, Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries (PRF-205), the Senegal and Mali reports for the three-country study of the potential impacts from new technologies and supporting policies were completed. The final report on Niger is well advanced and was completed in early 2002. The Niger project has been partially supported by ICRISAT. The farmer decision-making model was the same across these three countries and the technologies similar so the comparison and contrast will be instructive.

In 2001-02, the PRF-205 project had several additional sources of funding. One major activity was the Horn of Africa technology introduction, funded separately from PRF 205. Mr. Nega Wubeneh was funded for much of the year by special funds to evaluate the diffusion of *Striga*-resistant sorghum cultivars in Tigray. Moreover, with the uncertainty after Sept. 11, 2001 the project did not attempt to find another graduate student for this past budget year. So with the combination of the three above effects, spending activities during this project period practically stopped.

In the new budget year, the project will be resuming normal levels of activities. There are now two Ethiopian students being supported for their advanced degrees, Nega Wubeneh and Yigezu Atnafe. PRF-205 is keeping Tahirou Abdoulaye as a Post-Doc until at least February 2003, principally to work on a new marketing study in four Sahelian countries with Dr. Ouendeba Botorou. They have also contracted Liborio Cabanilla for three months in the fall to work on the economics of biotechnology in the Sahelian countries. There are three pressing issues here: the optimum level of research versus borrowing involvement in these new technologies; the economics of biosafety; and intellectual property rights. Levi (Liborio) will be traveling to four Sahelian countries plus Nigeria and Ghana. Tahirou will accompany him in the Sahelian countries.

In recent years the PI of PRF-205 has been engaged in several outside activities which have broadened his research interest and knowledge and helped expand the INTSORMIL program coverage. For much of the last two years, his team has worked on the Horn of Africa new-technology project; which has given intensive exposure to many of the six countries in the Horn. This gives a greater feeling of confidence about becoming more involved in field research in the Horn of Africa countries. Their early field specialization had been on the Sahel countries. During this budget year, the PRF-205 PI was involved in an evaluation of the economic impact of an eight-country project in North Africa and the Middle East. Technical inputs to this project were provided by ICARDA and IFPRI. The project was concentrated in the dryland crop and range areas in these countries. The relationship between wheat and barley in this region is similar to that between maize and sorghum in the Sahel. Also, the critical problem in the rangeland of common access and property ownership is also important for different activities in much of the INTSORMIL target region. These North African and Middle Eastern countries are also very concerned with many of the marketing problems that are important in INTSORMIL target regions. So this project should enable INTSORMIL to move into some new areas taking advantage of the experience in a higher-income region.

In West Africa, INTSORMIL's main collaborative agronomy research activities, UNL-213, have been focused in Mali and Niger. However, a memorandum of understanding was signed in 1999 with INERA, the NARS of Burkina Faso, and collaborative research was initiated in Burkina Faso. Under Memoranda of Agreements signed with ROCARS and ROCAFREMI, INTSORMIL also participates in the West and Central African Sorghum and Millet Research Networks. In research conducted during the past four years, it was determined that high-yielding grain sorghum genotypes that are tall or have high vertical leaf area distribution can be more competitive with weeds and, therefore, be a useful component of integrated weed management programs. Studies on management of late-maturing Maiwa pearl millet in southern Niger were initiated. Because this variety of pearl millet tillers profusely, it provides a unique opportunity to integrate grain production for human consumption and forage production to support livestock. Initial results that tillers can be harvested 65 to 85 days after planting for use as livestock feed without reducing grain or stover yield point to development of a more economically rewarding cropping system for millet farmers in the Sahel.

The UNL-213 project has been extremely productive in graduate education of West African collaborating scientists; agronomic research which has led to publication in scientific journals, the publication of extension bulletins, and the transfer of improved practices to pearl millet producers; and strengthening the activities of the West and Central Africa Pearl Millet Research Network. In the U.S. the project has documented the potential for pearl millet as a new grain crop in the Great Plains, and developed production practice recommendations for planting date, row spacing, and nitrogen fertilizer application. Research activities expanded from West Africa to Central America in 2001.

The major managerial issues facing Project UNL-213 is balancing INTSORMIL efforts with other responsibilities in National Research Systems and/or in U.S. universities. Although electronic communication has improved the situation, communication remains problematic both in planning and reporting research activities. There is continuing difficulty in identification of potential graduate students from West African and Central American countries largely due to the need for English language skills. Funding of graduate student studies is becoming increasingly difficult with flat budgets along with increased costs (especially overhead and stipend), and due to fewer supplemental funding opportunities from other sources. Although effective programs have been established, the future is somewhat uncertain due to the weak institutional strength of national programs. The pending merger of the West and Central Africa Pearl Millet and Grain Sorghum Research Networks has potential to enhance project activities. Nebraska research on pearl millet is severely constrained by the lack of a pearl millet breeding program in the Great Plains, and the lack of private sector investment in developing pearl millet as an alternate grain crop.

Activities to date of UNL-219 have addressed the INTSORMIL objectives of increased yield and improved institutional capacity. Collaborating researchers in Ethiopia are working with farmers to address production constraints associated with water deficits and low soil fertility. Tillage and implement options are being tested at various semi-arid sorghum production areas in Ethiopia. Tillage effects on organic matter and soil physical properties are being assessed for improved soil water management. In eastern Nebraska, soil fertility management options are being evaluated, including the use of starter fertilizers for no-till situations and the rotation effect of soybean on sorghum N nutrition. Phosphorus availability indices are being fine-tuned for soils of Nebraska, Ethiopia and Mozambique.

An INIA researcher from Mozambique has started his Master's degree program on soil fertility management at the University of Nebraska. Two researchers are being recruited for Master's degree studies at Alemaya University in Ethiopia.

Sustainable Plant Protection Systems

INTSORMIL's approach to developing sustainable plant protection systems is integrated pest management (IPM). Two key elements of IPM for sorghum and millet which are central to INTSORMIL plant protection research are genetic resistance of sorghum and millet to insect pests, pathogens, and the parasitic weed, *Striga*, and practices to control insects and pathogens with minimal use of chemical pesticides. INTSORMIL entomologists and plant pathologists work closely with plant breeders, agronomists and food scientists to develop more effective means to manage pests of sorghum and millet in order to provide higher yields of higher quality grain per unit area cultivated. Intensification of agricultural production, which can help remove pressure on fragile ecosystems, depends on many factors; sustainable, plant protection is essential to increase production of food and feed from sorghum and millet in economically and ecologically sustainable ways. In crop protection, a wide range of sources of resistance for insects, diseases, and *Striga* have been identified and crossed with locally adapted germplasm. This process has been improved immensely by INTSORMIL collaborators developing effective resistance screening methods for sorghum head bug, sorghum long smut, grain mold, leaf diseases and *Striga*.

Witchweeds (*Striga* spp.) are obligate parasitic weeds of significant economic importance. Control methods available to date have been costly and beyond the means of farmers in developing countries. While combining several control measures may be necessary to eradicate *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance. In the INTSORMIL project, *Striga* Biotechnology Development and Technology Transfer (PRF-213), the goal has been to exploit the unique life cycle and parasitic traits of *Striga* to develop sorghum lines that are resistant to *Striga* because of disrupted interaction between the parasite and the host. *Striga* research in PRF-213 employs a mix of biotechnological approaches towards understanding the genetic basis of *Striga* resistance and towards identification and enhancement of genetic variants that discourage *Striga* parasitism. Early work focused on the key biochemical signals required in germination of *Striga*. Recent emphasis has been on genetic mechanisms expressed at and post infection. In this report, we describe a study by Abdalla Mohamed who recently completed a Ph.D. dissertation characterizing "Hypersensitve Response to *Striga* Infection" as a strong defense mechanism. Hypersensitive response appears as a necrotic lesion at the point of parasitic attachment and discourages further penetration of the parasite into host roots. It is a highly heritable trait, and as such, serves as a powerful genetic trait that is readily incorporated into improved sorghum cultivars.

INTSORMIL's *Striga* research program is progressing well. Investigators in Project PRF-213 have made significant advances in the understanding of the biology of host parasite interaction in *Striga* parasitism. The work is exemplary and provides parallel for similar gains in maize and other crops. Collaborative linkages with ICRISAT and several NARS have been developed and strengthened. Training of NARS scientists is an important component of INTSORMIL's *Striga* research and development effort. Seed supply is likely to be a bottleneck in efforts to promote an expanded cultivation of these varieties. However, INTSORMIL received additional support in Year 22 to cooperate with the NARS of Ethiopia to organize and deliver a sorghum production technology package in *Striga*-affected areas in Ethiopia. This pilot project, currently underway in Ethiopia and implemented by supplemental funding from the Office of Foreign Disaster Assistance at USAID, promotes an integrated *Striga* control package that includes moisture conservation through use of tied ridging, nitrogen fertilizers, and *Striga* resistant sorghum cultivars in *Striga* endemic areas of the country. Primary focus of the project is the production and delivery of seed of *Striga* resistant sorghum cultivars to poor subsistence farmers through a community based seed multiplication and distribution scheme. The integrated package is aimed at demonstrating the enhanced benefit of *Striga* control through the added use of moisture conservation and fertility improvement.

In INTSORMIL's project on agroecology and biotechnology of stalk rot pathogens of sorghum and millet (KSU-210), collaborating investigators have collected important new populations of Fusarium, and new species have been identified. Some of these species are now being used in field tests on sorghum to determine their relative pathogenicity, primarily for stalk rot. Plans for cooperative work on grain mold of both millet and sorghum are being developed. Molecular diagnostic tools have been developed and should speed diagnoses. During the 2001-2002 year, the identification of fumonisin values for samples from village granaries has been a major accomplishment, as was the coordination required to obtain these samples. The species observed in these samples suggest that aflatoxins may be a major risk as well as moniliformin. Evaluations for moniliformin will be made during the coming year. Additional species have been identified, and remain to be described. Identifying the correct causal agent(s) for grain mold requires that, at the least, the major species being recovered be correctly identified, thus formal taxonomic descriptions of these new species needs to continue. Molecular diagnostic tools are being developed for these species, but validating them requires a sufficient sample to determine their validity. Studies of mycotoxin production under field conditions are needed, and the mycotoxigenic profiles of newly described species continue to need to be developed. The putative contamination of sorghum by a Fusarium mycotoxin problem in Japan, for example, indicates just how easy it is for even well-equipped 1st world laboratories to misidentify some of these compounds. As before species identification appears to be critical in estimating the risks posed by mycotoxins, and many of the Fusarium species common on sorghum do not make high levels of many of the common mycotoxins (but are toxic). We have begun a collaborative effort to identify mycoviruses that could be used as biological control agents for fungal pathogens of sorghum.

Investigators of project KSU-210 have also been carrying out systematic strain collection and strain identification; their development of AFLPs as a means to distinguish species should accelerate this process. The Principal Investigator has been on sabbatical leave from January 2001– August 2002, and work, while he has been gone, has focused on the continuing characterization of existing collections.

Toxicology work now requires a collaborator who can test the effects of toxins in commercial animal feeds and who can model their effects in laboratory systems, using human and animal cell lines as models.

The development of the Scientific Writing and Fusarium Laboratory workshops were not a part of the original planned activities, but have been a very successful outreach effort that will be continued. The Scientific Writing and Fusarium Laboratory workshops serve as interdisciplinary venues for scientists in developed and developing countries that work on various crops to exchange information and to interact with one another in an informal setting.

While on sabbatical leave the KSU-210 PI has edited the Proceedings of the INTSORMIL 2000 Sorghum and Millet Pathology Conference. This will require a continuing significant effort in the coming year. The total number of submissions (91) is well over twice that originally envisioned (35-40), and the final size is nearly 1200 pages of text and tables plus figures. Some manuscripts have required extensive editing for style, and others have required drastic cutting as they came in more than four times as long as the maximum requested in the initial guidelines.

INTSORMIL's project on agroecology and biotechnology of fungal pathogens of sorghum and millet from the Greater Horn of Africa (KSU-211) has changed its geographic focus to Central America. A short course was conducted at Kansas State for two collaborators, Ings. Reina Guzman (El Salvador) and Sergio Pichardo (Nicaragua). The laboratories in the host countries are being updated very slowly and much improvement remains as El Salvador and Nicaragua were involved in political strife for nearly twenty years. The objectives of the collaborative project are on schedule as were initially planned.

Advanced training and degrees are vitally needed to ensure future success of sorghum production in Central America. Due to budget constraints within INTSORMIL, other funding sources need to be investigated for support of Central American students. Student support for two semesters in the U.S. would partially alleviate training needs in the near future without potential problems of admittance for M.S. and Ph.D. students. The objectives of the collaborative project are on schedule as were initially planned.

MSU-205 research activities in Honduras, in collaboration with scientists at the Panamerican School of Agriculture (EAP), Zamorano, Honduras, were concluded in 2001. Students from the EAP were trained under MSU-205 and have returned to Central America to provide agricultural expertise. The extension of MSU-205 into Nicaragua and El Salvador in 1998 has provided MSU-205 the opportunity to investigate entomological constraints to sorghum production on large farms compared with the low input, subsistence farming systems in Honduras. The research collaboration with scientists in INTA, UNA, UNAN and Nicaraguan Grain Sorghum Producers Association (ANPROSOR) in Nicaragua and CENTA in El Salvador has proved to be extremely beneficial in developing plans and coordinating, implementing and conducting scientific investigations in these countries. Investigations of the specific insect pest problems identified in the respective countries have yielded the basic biological information needed for developing and recommending effective insect pest management programs.

This coordinated effort among scientists and administrators was particularly obvious in the planning and conduct of the Sorghum Crop Protection Workshop held in Managua in June 2002. In the United States, research investigations in 2001 and 2002 have been conducted or are in progress to determine levels of damage by fall armyworm on sorghum in different plant growth stages, as well as refining economic threshold levels for this lepidopterous pest on whorl stage plants and for sorghum midge on the panicles. This information will assist farmers in decision-making regarding the application of insecticides to control these pests.

The new INTSORMIL project (WTU-200), Sustainable Management of Insect Pests, with Dr. Bonnie Pendleton of West Texas A&M University as the principal investigator initiated its activities in the spring of 2002. As planned, the PI traveled to Southern Africa to review INTSORMIL activities in entomology, plant pathology, breeding, grain quality, and marketing and end use and establish collaborative research. The PI plans to travel to West Africa to review sorghum research in October 2002. Research on management of insect pests of sorghum and pearl millet was planned for with entomologists and other scientists in Botswana, Mali, and Niger. Communication and interaction were encouraged among scientists employed by the different agencies and in different countries within a region so research efforts would not be duplicated. Determination of the distribution of greenbug biotypes in Texas was begun and should proceed more rapidly this year. DNA from sorghum lines developed for resistance to different biotypes of greenbug was extracted and progress is being made to use AFLP to try to locate and map genes for resistance to different biotypes of greenbug. Thesis programs of four graduate students were directed during this reporting period. The students obtained very significant results from their research on greenbugs. Tiecoura Traore from Mali was identified to come to West Texas A&M University to learn English and begin graduate studies in IPM and entomology.

Utilization and Marketing

In the last couple years, INTSORMIL PRF-212 project has expanded their work on nutritional quality of sorghum from the extensive studies done with John Axtell on protein digestibility to include a research focus on starch digestibility of cooked and raw sorghum. They have verified preliminary data from 2000-2001 that shows the high protein digestibility mutant lines have correspondingly high starch digestibility using an in vitro digestion system with protease pretreatment followed by amylase digestion. Higher starch digestibility of the mutant sets it apart from the normal sorghum genotypes tested in this study and brings its digestibility to a comparable level to maize and rice. Moreover, normal cultivars tested with a range of protein digestibilities revealed cooked starch digestibility values ranked similarly. High starch digesting sorghum cultivars could be quite valuable for use in weaning and other foods where high energy availability is important. In the last two years, breeding work on the high protein digestibility mutant to convert it to a hard kernel type has been minimal due to the passing away of John Axtell. Lines have been carried forth and, as reported last year, a vitreous, hard kernel type was identified containing the mutant protein bodies. However, consistency and stability still seem to be problems. In the next year, a new effort at Purdue with Dr. Gebisa Ejeta will focus on this research problem. In India, the Mahyco Research Foundation project that finished in 2001 has also produced promising mutant lines. A chicken nutrition study showed mean true amino acid digestibilities for the mutant sorghum that were about 19% higher than the normal parent. The goal of PRF-212 is to find a way to improve protein and starch digestibility of sorghum grain in an acceptable kernel type.

PRF-212 is also interested in better understanding of some of the fundamental properties of sorghum components that affect textural properties of cooked foods. The goal is to identify ways to improve sorghum grain use in traditional and processed foods. In this regard, starch (amylopectin) structure of eight sorghum cultivars was different enough from that of maize and rice to lead to a hypothesis that the relatively hard gels of cooked, cooled sorghum pastes and rapid staling of sorghum flat breads, etc., may by linked to structure. Sorghum amylopectin, the large branched starch molecule, has comparably longer short linear chains that are involved in reassociation on cooling or storage to affect product quality.

The sorghum couscous/flour project in Niger progresses well, however this year there is no new data to report. The Cereal Technology group at INRAN has just completed a large-scale market test of pilot-plant production of high-quality flour, couscous, and degué (a breakfast food) from NAD-1 hybrid sorghum and is in the process of analyzing the data. They have entered into a collaboration with a few local entrepreneurs to get the product out into the marketplace.

With INTSORMIL's project on food and nutritional quality of sorghum and millet (TAM-226) there is also progress on several fronts. In Mali, an entrepreneur has produced N'Tenimissa, a white tan plant sorghum developed by the IER, under identity preserved marketing arrangements and has profitably sold decorticated sorghum in small packages. This occurred when the large bakery in Bamako did not want to continue use of sorghum flour in cookies because the Government had subsidized wheat flour. This is encouraging since the INTSORMIL TAM-226 project has worked for many years to encourage this concept. It is important that scientists learn that yield should be measured in terms of useful units of grain in order to produce economic returns to farmers.

New markets for value-enhanced white food sorghums are being promoted by the U.S. Grains Council from TAM-226 research on food sorghum processing and prototype products. In Japan, value-enhanced white food sorghums are processed into several commercial snack foods. Sorghum flour was demonstrated effectively in nearly 20 traditional Japanese foods by Japanese chefs and food processors.

Several mills are producing sorghum flour for niche markets in the U.S. Total use is still very low but new products for celiacs and ethnic foods exist.

In Central America, white sorghums are used in cookies and other products as a substitute for wheat or maize.

The antioxidant level in certain bran fractions of special sorghums is higher than that of blueberries. These special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products.

Several parental sorghum lines released from the Texas A&M program are used in commercial hybrids grown in Mexico and United States. ATx 635 hybrids have outstanding milling properties. The protein content of food sorghums is higher than that of other commercial sorghums. A dry milling technique can be used to determine the best milling sorghum to produce products with the lightest color.

Antifungal proteins appear related to grain mold resistance in sorghum. Mold resistance is necessary for improved food type sorghum production on a consistent basis.

TAM-226 activities in Honduras, El Salvador and Southern Africa are top priority. The opportunity to develop a more comprehensive program in El Salvador and Honduras is challenging because there is a lack of effective personnel with the knowledge required to do value-added processing research. TAM-226 will try to develop a relationship with Dr. Saldivar at ITESM in Mexico to help with the program in El Salvador. The NGO Activities at the University of Pretoria in South Africa continue. The chance to interact with a good cadre of Southern and East African students at University of Pretoria is a unique opportunity.

The uncertainty of funding from year to year inhibits commitments to graduate training. Inflation has eroded away much of our graduate training capabilities. The project utilizes significant research funded by other sources for the mold and breeding research support that is necessary for this project. Their ability to attract additional financial support for the work has allowed continued productivity. The funds from INTSORMIL have relatively little buying power since we have about the same number of total dollars we had 20 years ago.

The addition of new PIs working on breeding and molds at TAMU will help. Also the project on animal feeding and breeding at KSU will provide useful interaction.

Millet research has been minimized as funds from INTSORMIL decrease in actual buying power. Millet is not a crop in Texas and the leveraged funds from other sources are all for sorghum research.

The new INTSORMIL multidisciplinary project, KSU-220 (Enhancing the Utilization of Grain Sorghum and Pearl Millet through the Improvement of Grain Quality via Genetic and Nutrition Research) with Dr. Mitchell Tuinstra as principal investigator was subgranted in January, 2002. There are four components, KSU-220A (Sorghum/Millet breeding), KSU-220B (Poultry Nutrition), TAM-220C (Sorghum Breeding) and TAM-220D (Biotechnology). TAM-220C and TAM-220D were unable to access funds for 2001-02 until after the reporting period. These funds will be treated as carryover and will be spent in the 2002-03 reporting period. Although the inability to gain access to the INTSORMIL funds limited progress in some research areas, most of the research projects outlined in the proposal were initiated. Excellent progress was made on initiating nutrition research and germplasm characterization studies. Good progress has also been made on developing research plans with international collaborators in Africa and Central America. Lucius Bamaiyi, from Nigeria, and Soumana Souley from Niger have been identified and selected for graduate training, but due to the increased time now required to process foreign applications, will not be able to gain admission to TAMU and KSU before January 2003.

Biotechnology

Collaborative research of the INTSORMIL research team is proving useful to sorghum breeders worldwide. The use of DNA-based markers for genetic analysis and manipulation of important agronomic traits is becoming increasingly useful in plant breeding. In a recent study, 190 sorghum accessions from the five major cultivated races, namely bicolor, guinea, caudatum, kafir, and durra, were sampled from the world collection maintained by ICRISAT. Genetic variation was detected using RAPD primers. Only 13% of the total genetic variation was attributable to divergence across regions, but South African germplasm exhibited the least amount of genetic diversity, while the genetic diversity within the West African, Central African, East African and Middle Eastern regions was high among the 190 samples from the world collection. This research showed that molecular markers can be used to help identify suitable germplasm for introgression into breeding stocks. Selecting the most divergent accessions for introgression may increase the probability of extracting suitable inbred lines to improve the yields of varieties and hybrids. The INTSORMIL project PRF-205 has contracted Liborio Cabanilla for three months in the fall of 2002 to work on the economics of biotechnology in the Sahelian countries. There are three pressing issues here: the optimum level of research versus borrowing involvement in these new technologies; the economics of biosafety; and intellectual property rights. Levi (Liborio) will be traveling to four Sahelian countries plus Nigeria and Ghana to conduct this study.

Determination of the distribution of greenbug biotypes in Texas has begun and should proceed more rapidly this year. DNA from sorghum lines developed for resistance to different biotypes of greenbug was extracted and progress is being made to use AFLP to try to locate and map genes for resistance to different biotypes of greenbug. DNA from sorghum lines developed for resistance to different biotypes of greenbug was extracted and progress is being made to use AFLP to try to locate and map genes for resistance to different biotypes of greenbug. Thesis programs of four graduate students were directed during this reporting period. The students obtained very significant results from their research on greenbugs. Investigators of project KSU-210A have also been carrying out systematic strain collection and strain identification; their development of AFLPs as a means to distinguish species should accelerate this process. This research team plans to purchase equipment to automate much of this process during the coming year.

In INTSORMIL's project on agroecology and biotechnology of stalk rot pathogens of sorghum and millet (KSU-210), collaborating investigators have collected important new populations of Fusarium, and new species have been identified. Some of these species are now being used in field tests on sorghum to determine their relative pathogenicity, primarily for stalk rot. Plans for cooperative work on grain mold of both millet and sorghum are being developed. Molecular diagnostic tools have been developed and should speed diagnoses.

In this reporting year, INTSORMIL advertised for a biotechnology project. The proposal which most completely met the INTSORMIL needs and terms of reference was a component of the new Multidisiplinary project, KSU-220. This activity will conduct research on developing and characterizing recombinant inbred (RI) sorghum mapping populations to identify markers for grain mold resistance, anthracnose resistance, and improved nutritional characteristics. The project will convert RAPDs and AFLPs linked to grain-mold resistance in the sorghum variety, Sureño, to more useful sequence-tagged site markers. A library of potential mold-resistance induced genes from subtracted-suppressive-hybridization experiments will be established. The multidisciplinary team will evaluate the feasibility of marker-assisted selection for grain mold resistance.

Future Directions

Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raise incomes. With its increasing strength of scientific expertise in developing countries, INTSORMIL is now able to more effectively reduce constraints to production and utilization of sorghum and millet to the mutual benefit of developing countries and the United

States. Advances in sorghum and millet research over INTSORMIL's first 22 years and the training of sorghum and millet scientists by INTSORMIL in the United States, Africa and Central America now enable scientists from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are keys to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds a finite scientific capability on sorghum and millet, and creates technological and human capital that have a sustainable and global impact.

In the past, INTSORMIL focused a major part of its resources on graduate student training and generating research particularly useful within the scientific community. The INTSORMIL agenda for the future continues to include graduate student training and generation of scientific knowledge and information to scientists, but will be more focused and directed toward users of the technology generated by INTSORMIL research. Future strategies of INTSORMIL will maintain INTSORMIL's current, highly productive momentum, build on its record of success, and accomplish a new set of goals. INTSORMIL's global strategy for 2001-2006 is intended to contribute to the shift of sorghum and pearl millet from subsistence crops to value-added, cash crops, and proposes to produce scientific knowledge and technologies to: contribute to economic growth, improve nutrition, increase yield, and improve institutional capability to meet global, regional and national needs.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-210
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Summary

In collaboration with my South African colleagues we have evaluated fumonisin levels from seven pearl millet and seven sorghum samples collected from village granaries in rural Mali. Samples (13 of 14) contained 5-70 ng/g (ppb) fumonisins, while the 14th contained > 1000 ng/g total fumonisins and could pose a human health hazard. Many of the *Fusarium* spp. from these samples do not belong to presently described *Fusarium* species. In collaboration with my Australian colleagues, we have described a new *Gibberella* species that causes stalk rot of sorghum from collections in the Philippines and Central America. This species is distinguished from other *Gibberella* species by its long, slender ascospores, and also can be recovered from diseased maize and sugarcane. We also expanded the genetic map of *Fusarium verticillioides* through the addition of approximately 500 Amplified Fragment Length Polymorphism (AFLP) markers.

Objectives, Production and Utilization Constraints

Objectives

- Increase collection of fungal samples from sorghum and millet, especially grain, and identify the species recovered.

- Develop characters, such as mating type, for assessing genetic variability in fungal populations.

- Provide pure cultures of fungi from our extensive collection to U.S. and LDC investigators to expedite diagnoses of fungal diseases of sorghum and millet.

- Determine mycotoxigenic potential of *Fusarium* spp. from sorghum and millet.

- Conduct Scientific Writing and *Fusarium* identification training workshops.

Constraints

Fusarium spp. associated with sorghum and millet do obvious damage as stalk rot, grain mold and pokkah boeng. All of these diseases can cause intermittently heavy losses in the United States and in developing countries. Breeding for resistance to *Fusarium* associated diseases is limited because the strains responsible for disease often cannot be accurately identified and used repeatedly in field challenges. Correct identification of the fungi colonizing and causing disease is essential for the design of breeding and control measures. Without a thorough understanding of the pathogen's genetic diversity and population dynamics, effective control measures are difficult to design and resistant lines may have unexpectedly brief lives.

Mycotoxin contamination limits the uses to which harvested grain can be put, and creates health risks for both humans and domestic animals. *Fusarium*-produced mycotoxins are among the most common mycotoxins found in cereal grains, yet have not been effectively evaluated in sorghum and millet. Since contamination often occurs on apparently sound grain, merely discarding obviously molded grain is not sufficient to avoid the mycotoxicity problems.

Research Approach and Project Output

Research Methods

Grain samples and fungal cultures. Sorghum and pearl millet grain samples were collected in rural Mali with the assistance of IER and World Vision personnel in September 2001. The grain samples were shipped via courier to the PROMEC (Medical Research Council) laboratories in Tygerberg, South Africa for analysis for evaluation of their mycotoxin content with standard high pressure liquid chromatography (HPLC) and liquid chromatography/mass spectrometry (LC/MS) protocols. Fungi were recovered from these samples at KSU by plating on a peptone-PCNB medium that enriches for *Fusarium* spp. Strains were routinely cultured on carnation leaf agar, or on modified Czapek's complete medium. Strains are maintained in long-term storage as spore suspensions in 15% glycerol frozen at -70°C.

Samples of *Gibberella sacchara* examined are from the KSU culture collection. The first of these strains received were from China and Brazil in the mid 1980s, from sugarcane in Taiwan and sorghum in Brazil, respectively. Additional confirmed isolates from sorghum include strains collected by Larry Claflin from El Salvador this past year, and strains that I collected from the Philippines in 1989. In diagnostic crosses we used the following standard *Gibberella fujikuroi* mating population mating-type tester strains from the KSU collection or from the Fungal Genetics Stock Center, Kansas City, Kansas: FGSC 7600 (*MATA-1*), FGSC 7603 (*MATA-2*), FGSC 7611 (*MATB-1*), FGSC 7610 (*MATB-2*), KSU C-01993 (*MATC-1*), KSU C-01995 (*MATC-2*), FGSC 7615 (*MATD-1*), FGSC 7614 (*MATD-2*), FGSC 7616 (*MATE-1*), FGSC 7617 (*MATE-2*), FGSC 7057 (*MATF-1*), FGSC 7056 (*MATF-2*), KSU G-05111 (*MATG-1*), KSU G-05112 (*MATG-2*), KSU H-10847 (*MATH-1*) and KSU H-10850 (*MATH-2*).

Strains used in the expanded genetic map were the same as those used for the original genetic map of this organism that was based on restriction fragment length polymorphisms (RFLPs); see the 1995 INTSORMIL Annual report for further details.

Microscopic observations. Perithecia were treated with 3% KOH and 100% lactic acid to observe any color reaction, and measured *in situ.* Asci and ascospores were mounted in water for measurement and photography. Measurements were taken of 20 each of perithecia, asci, and ascospores. Whole perithecia were fixed in 6.5% glutaraldehyde in 100 mM sodium cacodylate buffer at pH 7.6 for 4 h at room temperature, dehydrated in a graded ethanol series, and finally infiltrated and embedded in LR White resin. Sections, 1.5 m thick, were cut with a Reichert ultramicrotome, dried onto poly-l-lysine-coated glass slides, and stained with 0.5% Toluidine Blue *O* for 10 sec. Sections were mounted in immersion oil.

Amplified Fragment Length Polymorphisms (AFLPs). Cultures were grown and DNA was extracted as previously described (see 2000 INTSORMIL annual report). AFLPs were generated by using a protocol we have modified from the standard for these fungi (see 2001 INTSORMIL annual report). Most polymorphisms were characterized as presence/absence of bands although a few occurred in which the polymorphism appeared as an apparent difference in molecular weight. To analyze AFLP profiles, we manually scored the presence or absence of 486 polymorphic bands generated by 37 AFLP primer pairs (3-23 polymorphic bands per primer). We also identified polymorphic bands through bulk-segregant analysis that generated an additional 18 AFLP primer pairs that map near the gene cluster that includes the fumonisin biosynthetic genes and placed these markers on the map as well. We assumed that bands of the same molecular size in different individuals were identical. Each band was treated as a single independent locus with two alleles and unresolved bands or missing data were scored as ambiguous.

Genetic map construction. Genetic mapping of all characters was performed with Map Manager QTX11 (http://mapmgr.roswellpark.org/mmQTX) on a Macintosh G4 Power PC computer. The data were treated by the mapping program as a backcross with codominant markers, paternal parent unique, for accurate analysis of this haploid genome. The data from the map of Xu and Leslie were imported into Map Manager from Map Maker and used to reconstruct the previous linkage map. Marker data from the AFLP analysis was then imported into the program and combined with the previous data. The distribute function was used to assign map positions to the AFLP markers. Following the initial linkage group analysis, we inspected the aligned phenotype data visually to minimize linkage distance based on the assumption that single-locus double recombinants were highly unlikely and probably result from gene conversion, or from errors in scoring or bookkeeping.

Research Findings

Fumonisins in sorghum and pearl millet from Mali. The fumonisin analyses for sorghum and pearl millet are the first definitive analyses for these toxins from anywhere in the world (Table 1). The Joint FAO/WHO Expert Committee on Food Additives has set a provisional Maximum Tolerable Daily Intake of 2 μg/kg of body weight. The risk posed by these toxins depends on both quantity of grain consumed and the amount of toxin that it contains. Although the grain from sample 16 probably poses a significant health hazard, the grain from the other 13 samples probably does not, at least in terms of fumonisin toxicity. Analysis of the moniliformin levels from all 14 samples is in progress. Given these results, collection of grain samples, especially those stored on-farm or in village granaries is needed to confirm their general safety with respect to these mycotoxins.

Analysis of the fungal contaminants of these grain samples is in progress. At least four *Fusarium* species have been

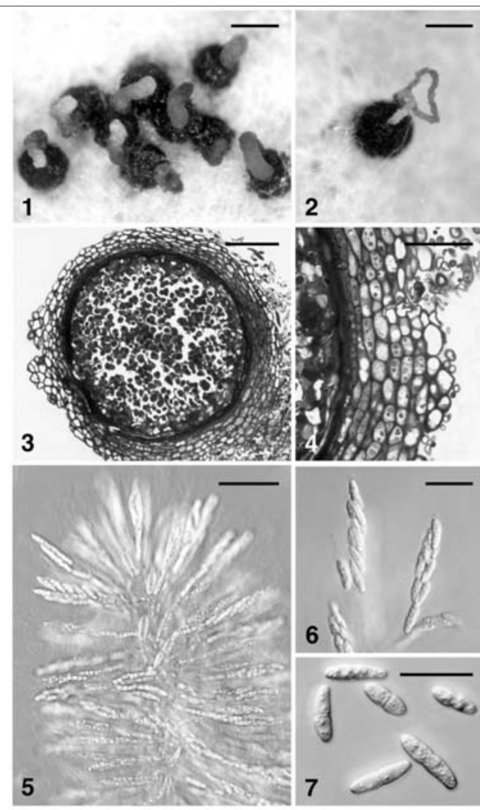
Table 1. Fumonisin and *Fusarium* species analyses of sorghum and pearl millet grain samples from Mali.

Sample	Location	Fusarium Cultures[1]	Fumonisins[b]			
			FB_1	FB_2	FB_3	Total
Sorghum						
3	Marka Coungo market – 2000 crop	81	10	ND	ND	10
5	Fana market – 2000 crop	80	35	5	ND	40
9	Dakoumani, solarized – 2000 crop	50	10	ND	ND	10
10	Dakoumani, insecticide treated – 2000 crop	60	20	ND	ND	20
12	Douna, insecticide treated – 1997 crop	30	15	ND	ND	15
14	Kondogola – 1998 crop	47	25	ND	ND	25
16	Cinzana-Gare, "barique" storage – 2000 crop	55	360	345	320	1025
Pearl Millet						
2	Marka Coungo market – 2000 crop	58	25	ND	ND	25[c]
4	Fana market – 2000 crop	100	55	10	5	70[c]
6	Dakoumani – 1999 crop	54	17	ND	ND	17[c]
7	Dakoumani – 2000 crop	68	20	ND	ND	20
11	Douna, insecticide treated – 1995 crop	48	5	ND	ND	5
13	Kondogola – 1998 crop	64	15	ND	ND	15
15	Cinzana-Gare – 2000 crop	69	15	ND	ND	15

[a]Number of cultures of *Fusarium* spp. Cultures are not yet identified to species.
[b]Detection limit for HPLC analyses is 5 ng/g.
[c]HPLC results confirmed with LC/MS.

identified thus far, and strains belonging to at least three other species, at least one of which is undescribed, have been identified as well. The medium on which the subcultures were made is selective for *Fusarium* spp., but other fungi occasionally can be identified as well. In this set of samples, contamination with *Aspergillus* spp. was much higher than normal, and it is possible that mycotoxins produced by these fungi, e.g., aflatoxins and ochratoxin, also may be present at significant levels.

G. sacchara. English version of formal species description: Perithecia superficial, solitary to aggregated in groups of a few and seated on a minute stromatic base, obovoidal, and warty (Figs. 1 and 2); 270-390 (mean = 325) µm × 250-390 (mean = 310) µm diam; blue-black, color not changing in 3% KOH, turning red in 100% lactic acid. Perithecial wall 23.1-38.9 (mean = 30.6) µm wide laterally, formed of two obvious regions (Figs. 3 and 4). Outer wall region 18.4-33.0 (mean = 25.6) µm wide; outer cells ± angular to elliptic, 5.3-11.5 (mean = 8.4) µm length × 3.1– 5.9 (mean = 4.3) µm width, with the largest cells at the exterior and the smallest cells toward the interior of the wall, walls of cells 0.5-1.2 (mean = 0.9) µm wide and pigmented. Inner wall region 4.0-5.9 (mean = 4.9) µm wide; cells ± angular to elliptic, 7.2-16.3 (mean = 10.6) µm length × 1.1-3.2 (mean = 2.2) µm width. Cells fusiform, thin-walled and irregular, walls of inner cells 0.3-0.6 (mean = 0.4) µm wide and pigmented (Fig. 4). Outer and the inner wall regions merging imperceptibly; cells of the outer region more pigmented. Perithecial apex continuous with the outer and inner wall layers; cells at the apex smaller appearing as a reticulum; cells forming the ostiolar opening ± clavate and thick walled at the cell tips, non-pigmented merging periphyses. Cells of the apex attaining the same length to form an apical disk. Asci fusiform (Figs. 5 and 6), regularly dehiscing upon examination under the microscope and 8 spored. Ascospores



Figures. 1-7. ***Gibberella sacchara*** **produced from a cross of strains B-03852 × B-03853 on carrot agar. 1, 2. Perithecia. 3. Transverse section of a perithecium stained with toluidine blue. 4. Close up of transverse section of perithecial wall. 5, 6. Asci. 7. Ascospores. Scale bars: 1 and 2 = 200 µm; 3 and 5 = 50 µm; 4, 6 and 7 = 25 µm.**

exuded in a cirrhus (Figs. 1 and 2), ellipsoidal to obovoid with both ends rounded, 0-1 septate and slightly constricted at the septum, 3-4.5 (mean = 4.2) × 7.0-8.0 (mean = 7.6) µm (Figs. 5-7). Heterothallic species reproductively isolated from previously described species of *Gibberella*.

This species is most easily differentiated from other *Gibberella* species by its much larger and slenderer ascospores. The species is associated with sorghum stalk rot and has been recovered from leaf spots on sorghum plants. It also attacks other domesticated crops, *e.g.,* maize and sugarcane; however, no comprehensive studies of host range or pathogenicity have been conducted with this fungus. This species is most commonly seen in wet tropical and semi-tropical regions. We have no strains from temperate, arid or semi-arid regions at this time. Strains in this species are most easily confused with *Fusarium subglutinans*, and reports in the older literature of *F. subglutinans* or of *F. moniliforme* var. *subglutinans* from wet tropical and subtropical regions probably refer to this species. Strains of this species are not known to make fumonisins.

Genetic map of *G. moniliformis*. Of the AFLP bands scored in this mapping population, 25-30% were polymorphic, which is consistent with results on relatedness between two members of the same species in the *G. fujikuroi* species complex. The distribution of markers from individual primer pairs appears to be random with respect to chromosome. The major architectural features of the previous Xu and Leslie map remain unchanged (Table 2), and the present map has 636 markers that define 580 genetic loci (Fig. 8).

The update increases the total map length by approximately 50% (736 cM), while correspondingly reducing the average number of kb/cM from 32 to 21. The maps for linkage groups 11 and 12, in particular, are much denser. The average distance between identified markers has been reduced from 10 cM/interval to 3.4 cM/interval. The number of gaps greater than 20 cM in length has been reduced from 24 to five, with no interval larger than 29 cM. The remaining gaps tend to be on the distal portions of chromosomes, which remain to be identified, probably through the use of telomere probes. The distribution of the number of crossovers per chromosomes (Table 2) appears to be random (^{2} test, , $p = 0.05$). The physical size of the chromosome is not strongly correlated with the number of markers ($r = 0.72$), the number of loci ($r = 0.71$), or the length of a chromosome in map units ($r = 0.68$).

Some important gaps remain even in this relatively saturated map. One end of chromosome 5 now has eight markers that are in a cluster separated by 26 cM from the next nearest locus. Other large recombination gaps exist on chromosome 1 (21 cM) and at the ends of chromosomes 7, 8 and 10 (Fig. 8). The 10 terminal markers of chromosomes 2, 4, 7, 8 and 10 add ~120 cM to the genetic map, and elimination of these markers would reduce the average map distance to 3.2 cM/marker. Even with these large gaps the map appears to be relatively saturated as 56 loci (10%) are represented by more than one marker. The addition of more randomly selected markers is probably not an effective use of resources at this time, as only centromeres, telomeres, and a few, primarily terminal, chromosome regions remain in need of further definition at this level.

Networking Activities

Editorial and committee service (2001)

- Editor of Applied and Environmental Microbiology
- Member of the International Society for Plant Pathology, Fusarium Committee

Research Investigator Exchange

Dr. Leslie made the following international scientific exchange visits (2001)

Australia – October 10-14
Egypt – April 25 – May 4
Ghana – September 7-12
India (ICRISAT) – September 28 – October 6

Table 2. Comparison of the linkage map of Xu and Leslie with the updated map.

		Xi amd Leslie		Updated map			Crossovers per chromosome						
Chromosome	Physical chromosome size (Mb)	No. of markers	cM	No. of markers	No. of markers	cM	0	1	2	3	4	5	Mean
1	10	15	173	77	65	241	7	32	32	27	10	13	2.5
2	6.5	15	196	53	51	189	10	39	38	14	14	6	2.1
3	4.9	15	90	58	51	190	20	44	22	13	10	12	2.0
4	4.1	14	120	62	56	214	15	27	43	18	8	10	2.2
5	4.0	11	110	48	45	189	17	20	35	28	11	10	2.1
6	3.6	13	146	68	61	195	20	40	30	11	9	11	1.9
7	3.0	12	113	50	42	169	20	38	31	20	7	5	1.8
8	2.6	14	134	49	44	184	15	35	38	21	7	5	1.7
9	2.5	10	132	49	44	173	21	41	28	18	3	10	1.8
10	2.2	14	137	60	53	216	9	39	31	15	17	10	2.0
11	2.0	6	86	42	38	150	19	50	33	11	74	4	1.6
12	0.7	4	15	20	13	78	69	27	5	12	3	1	0.8
Total	46.1	143	1452	636	568	2188	248	441	357	308	101	96	1.9

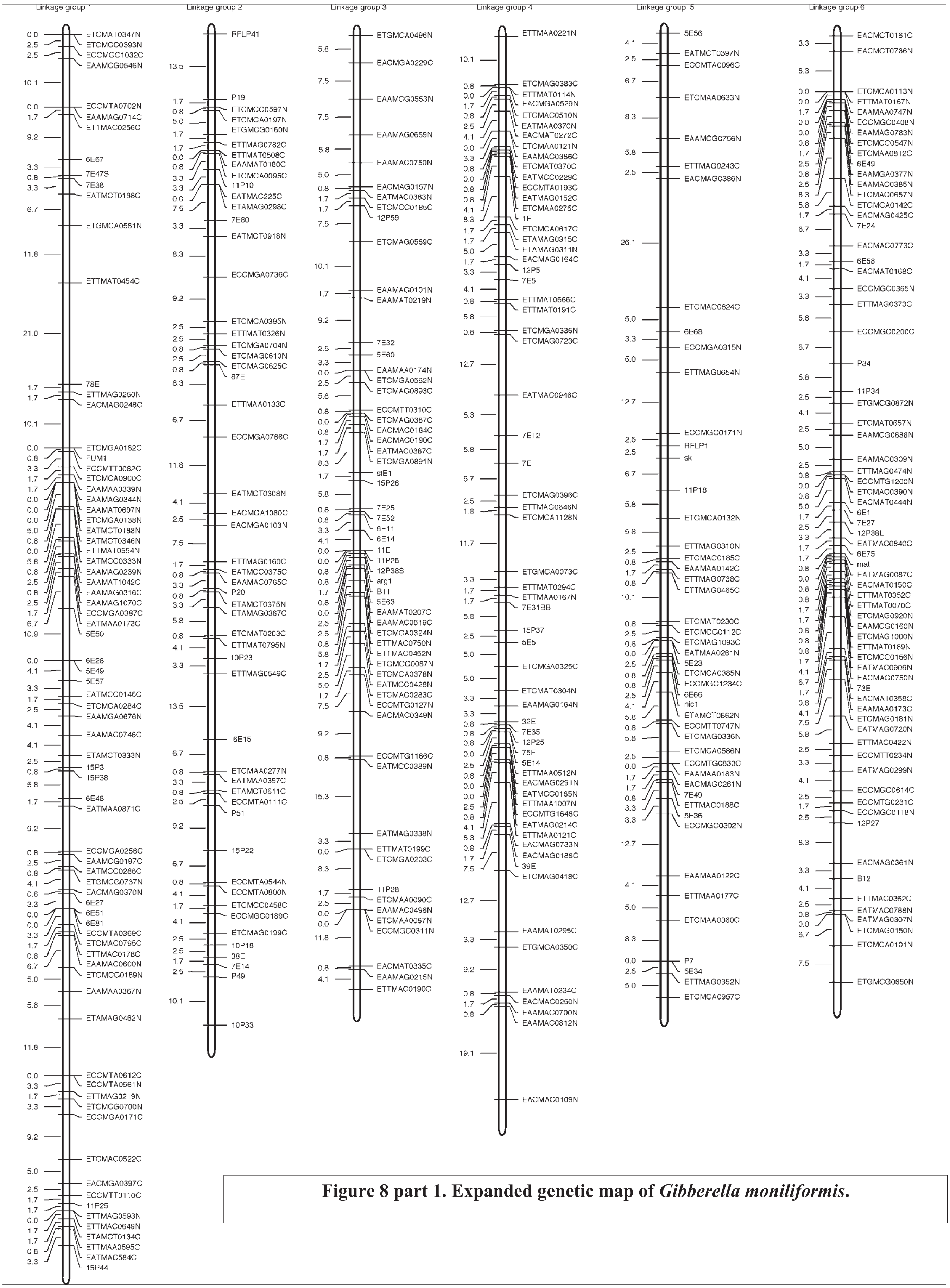


Figure 8 part 1. Expanded genetic map of *Gibberella moniliformis*.

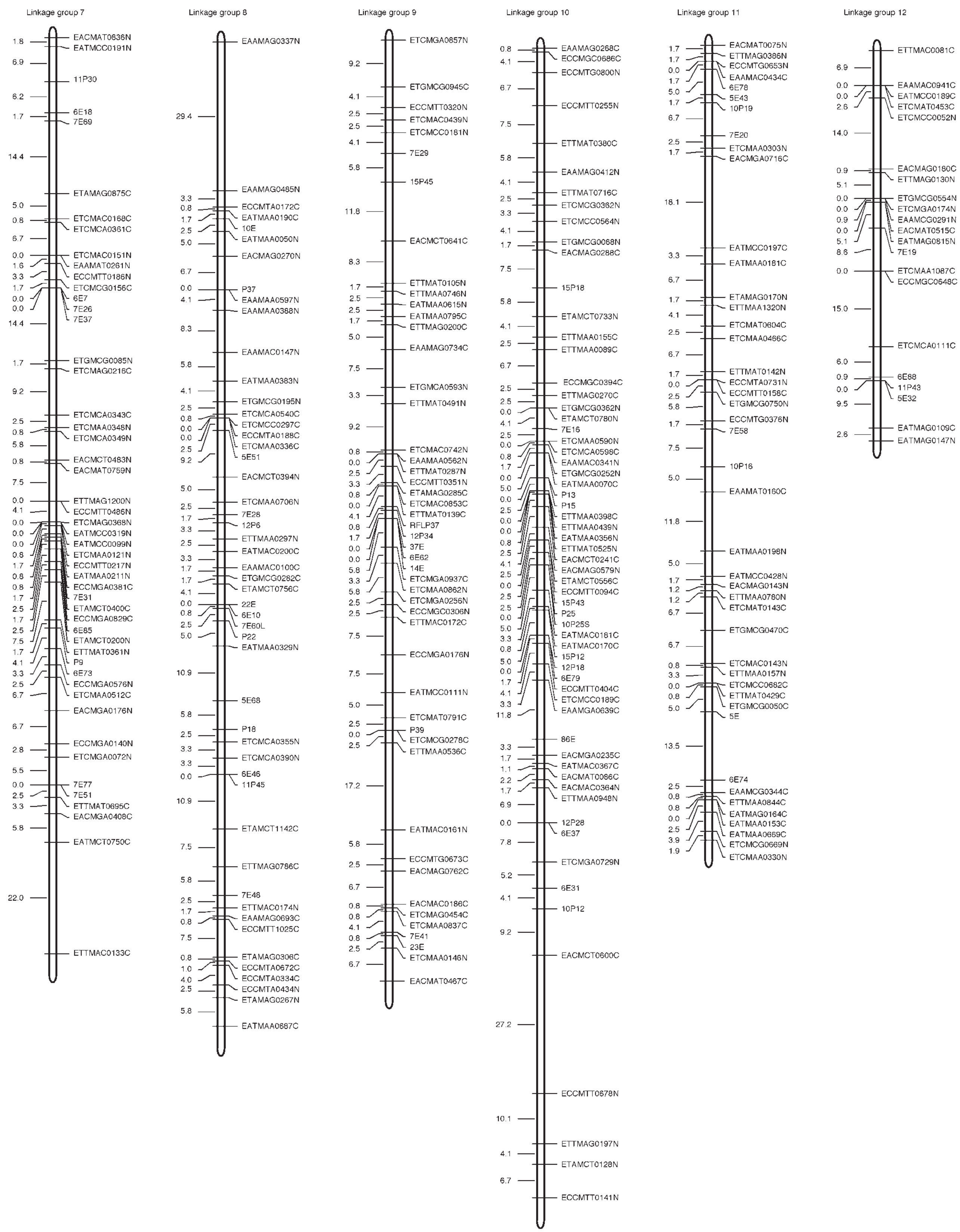


Figure 8 - part 2. Expanded genetic map of *Gibberella moniliformis*.

Mali – September 1-7
Malaysia – October 7-9
Mozambique – October 28-31

South Korea – October 14-18
South Africa – November 1-20

Seminar, Workshop & Invited Meeting Presentations (2001)

- Organized *Fusarium* Laboratory Workshop in Manhattan from June 10-15; 28 participants and five instructors from eight countries.
- Editor for Proceedings of Sorghum/Millet pathology conference in Guanjuato, Mexico.
- 22nd National Grain Sorghum Producers Conference, Nashville, Tennessee – 2/01.
- Department of Botany and Plant Pathology, Purdue University, West Lafayette, Indiana – 2/01.
- Egyptian National Agricultural Library, Dokki, Egypt – 04/01.
- Savanna Agricultural Research Institute, Tamale, Ghana – 09/01.
- ICRISAT, Patancheru, India –10/01.
- Department of Plant Pathology, Seoul National University, Seoul, South Korea – 10/01.
- FABI, University of Pretoria, Pretoria, South Africa – 11/01.
- Summer Grain Crops Institute, Agricultural Research Council, Potchefstroom, South Africa – 11/01.
- Institute of Wine Biotechnology, Stellenbosch University, Stellenbosch, South Africa – 11/01.
- During 2001 *Fusarium* cultures were provided to:
- Drs. Charles Bacon and Ida Yates, USDA Russell Research Center, Athens, Georgia.
- Drs. Robert L. Bowden, Larry E. Claflin, Louis A. Heaton & Douglas J. Jardine, Department of Plant Pathology, Kansas State University, Manhattan, Kansas.
- Dr. S. Chulze, Universidad Nacional de Rio Cuarto, Rio Cuarto, Argentina.
- Drs. Anne E. Desjardines and Ronald D. Plattner, Mycotoxin Research Unit, National Center for Agricultural Utilization Research, USDA/ARS, Peoria, Illinois.
- Dr. Elhamy M. El-Assiuty, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt.
- Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, Kansas.
- Dr. D. Geiser, Department of Plant Pathology, Pennsylvania State University, University Park, Pennsylvania.
- Dr. L. Hornok, Agricultural Biotechnology Center, Institute for Plant Sciences, Godollo, Hungary.
- Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea.
- Drs. A. Logrieco and A. Moretti, Istituto Tossine e Micotossine da Parassiti Vegetali, Bari, Italy.
- Dr. W. F. O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa.
- Dr. H. I. Nirenberg, Biologische Bundesantsalt für Land- und Forstwirtschaft, Berlin, Germany.
- Dr. Amir Sharon, Department of Plant Sciences, University of Tel Aviv, Tel Aviv, Israel.
- Dr. J. S. Smith, Department of Animal Sciences and Industry, Kansas State University, Manhattan, Kansas.
- Dr. Brett Summerell, Royal Botanic Gardens-Sydney, Sydney, Australia.
- Dr. Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.
- Drs. M. Wingfield and B. Wingfield, Forestry and Agricultural Biotechnology Institute, University of Pretoria, Pretoria, South Africa.

Other Collaborating Scientists

- Dr. Lester Burgess, Faculty of Agriculture, University of Sydney, Sydney, Australia.
- Dr. Sofia Chulze, Department of Microbiology, National University of Rio Cuarto, Rio Cuarto, Argentina.
- Drs. M. Flieger and S. Pazoutova, Institute of Microbiology, Czech Academy of Sciences, Prague, Czech Republic
- Dr. Laszlo Hornok, Agricultural Biotechnology Center, Godollo, Hungary.
- Dr. Sandra Lamprecht, Plant Protection Institute, Agricultural Research Council, Stellenbosch, South Africa.

- Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea.
- Drs. Antonio Logrieco and Antonio Moretti, Istituto Tossine e Micotossine da Parassiti Vegetali, CNR, Bari, Italy
- Dr. Anaclet S. B. Mansuetus, Department of Biological Sciences, University of Swaziland, Kwaluseni, Swaziland.
- Dr. Neal McLaren, Agricultural Research Council, Potchefstroom, South Africa.
- Dr. Maya Piñeiro, Mycotoxins Unit, Laboratorio Tecnologia del Uruguay, Montevideo, Uruguay.
- Prof. Baharuddin Salleh, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia.
- Dr. Brett A. Summerell, Royal Botanic Gardens, Sydney, Australia.
- Drs. Michael and Brenda Wingfield, FABI, University of Pretoria, Pretoria, South Africa.
- Drs. Charles W. Bacon and Ida Yates, USDA Russell Research Center, Athens, Georgia.
- Drs. A. E. Desjardins & R. D. Plattner, USDA National Center for Agricultural Utilization Research, Peoria, Illinois.
- Dr. K. K. Klein, Department of Biological Sciences, Mankato State University, Mankato, Minnesota.
- Dr. G. N. Odvody, Texas Agricultural Experiment Station, Corpus Christi, Texas.

Publications and Presentations

Journal Articles, Books and Book Chapters

Leslie, J. F. 2001. Population genetic level problems in the *Gibberella fujikuroi* species complex. In: Fusarium*: Paul E. Nelson Memorial Symposium* (B. A. Summerell, J. F. Leslie, D. Backhouse and W. L. Bryden, eds.), pp. 113-121. APS Press, St. Paul, Minnesota.

Leslie, J. F. and W. F. O. Marasas. 2001. *Fusarium* in sorghum: Life in interesting times. *Proceedings of the 22nd Sorghum Improvement Conference of North America (Nashville, Tennessee)*, pp. 76-83.

Leslie, J. F., K. A. Zeller and B. A. Summerell. 2001. Icebergs and species in populations of *Fusarium*. *Physiological and Molecular Plant Pathology* 59: 107-117.

Marasas, W. F. O., J. P. Rheeder, S. C. Lamprecht, K. A. Zeller and J. L. Leslie. 2001. *Fusarium andiyazi* sp. nov., a new species from sorghum. *Mycologia 93:* 1203-1210.

Summerell, B. A., J. F. Leslie, D. Backhouse, W. L. Bryden and L. W. Burgess, eds. 2001. Fusarium*: Paul E. Nelson Memorial Symposium*. APS Press, St. Paul, Minnesota. 392 pp.

Abstracts

Alexander, N. J., R. D. Plattner, R. L. Bowden and J. F. Leslie. 2001. Linkage of molecular markers with trichothecene genotypes in *Gibberella zeae*. *Fungal Genetics Newsletter* 48(Suppl.)**:** 158.

Leslie, J. F., K. A. Zeller, A. Logrieco and A. Moretti. 2001. Species diversity and genetic variation among *Fusarium* isolated from prairie grasses. *Phytopathology* 91**:** s54.

Vargas, J. I., R. L. Bowden, K. A. Zeller and J. F. Leslie. 2001. Comparisons of North and South American populations of *Gibberella zeae*. *Phytopathology 91:* s91.

Zeller, K. A., J. E. Jurgenson, and J. F. Leslie. 2001. Simultaneous mapping of multiple *vic* loci in *Gibberella fujikuroi* Mating Population A (*Fusarium verticillioides*). *Phytopathology* 91: s99.

Agroecology and Biotechnology of Fungal Pathogens of Sorghum and Millet

Project KSU-211
Larry E. Claflin
Kansas State University

Principal Investigator

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Dr. Mitch Tuinstra, Department of Agronomy, Kansas State University, Manhattan, KS

Summary

A sorghum growth model was coupled with ergot prediction model developed in South Africa to evaluate ergot potential on a specific maturity genotype at different planting dates in a specific environment. Thirty years (1970-1999) of consecutive climatic data from weather stations in Concordia, Dodge City, Manhattan, Russell, Topeka, and Wichita, Kansas and Grand Island, Nebraska were utilized in the model. Ergot potentials varied among locations primarily due to planting date and/or mean maximum RH during anthesis. Most planting dates recommended for each location would result in limited or no incidence of ergot based on our model. Late planting dates increased the risk of infection.

Objectives, Production and Utilization Constraints

Objectives

- U.S./Mexico/Nicaragua/El Salvador: Determine the prokaryotic plant pathogenic organisms responsible for unique and unusual diseases of sorghum that may pose yield constraints. These causal agents are primarily insect disseminated and a joint collaborative project has been implemented with project MSU-205.

- U.S./Kenya: Continue to screen for genetic variability of sorghum germplasm to covered kernel smut and ergot diseases that continually occur and affect the nutrition of people and animals.

- U.S./Mexico/Nicaragua/El Salvador: Ascertain the prevalence of diseases through surveys and use of the ADIN nursery from Texas A&M University.

- U.S./Mexico: Collaborate with Mr. Jesus Narro on a bacterial disease project of sorghum in the Bahel region of Mexico.

- Determine if physiological resistance rather than pollen management is the mechanism for tolerance to *Claviceps africana*.

- Continue to evaluate screening protocols for determining genetic variability of grain sorghum to sooty stripe disease (*Ramulispora sorghi*). Determination of various environmental parameters to maximize incidence and severity of disease will also be included.

Constraints

Ergot (sugary disease) of sorghum (*Sorghum bicolor* (L.) Moench), caused by *Claviceps africana* was only a problem in grain sorghum in Africa and Asia prior to 1996 when the disease was first detected in Brazil and Argentina. In 1997, ergot was found in Colombia, Honduras, Nicaragua, El Salvador, Mexico, numerous islands in the Caribbean, and in the U.S. (Kansas, Nebraska, and Texas). The sudden, widespread appearances of ergot in recent years demonstrate the potential impact of *C. africana* on the sorghum industry worldwide.

Ergot is a disease of unfertilized sorghum ovaries The stigma is the principal site of the infection. Susceptibility to infection is from floral gaping, just before or at anthesis. Infected spikelets exude sweet, sticky drops of fluid honeydew containing three types of conidia: macroconidia, secondary conidia, and microconidia. Wind dissemination of secondary conidia is the most important mode of dispersal for local and long distance spread of *C. africana* and may explain the rapid, long-distance disease spread in Australia and the Americas.

Germplasm resistant to ergot have been identified in numerous reports, but these lines are mostly photoperiod-sensitive, tall and agronomically undesirable. Environmental interactions have also limited the use of these accessions in breeding because germplasm reported as resistant in one environment was susceptible in a different geographical location or environment. We evaluated various accessions of *Sorghum* spp. and potential grass hosts for their reaction to ergot under greenhouse conditions at Manhattan, KS.

The development and use of a disease forecasting system based on weather data (temperature, humidity, rainfall, solar radiation, etc.) and host factors and performance (pollen production and viability, stigma receptivity, nicking, etc.) could be most useful in managing ergot. Use of predictive models have been used for other crops to optimize chemical applications. Models to predict ergot in sorghum were developed by McLaren and Flett in South Africa and Wang et al., in Australia. McLaren's model may not be applicable to geographical regions other than those in South Africa because the relationships were based on a fixed number of days to characterize the start and duration of both the flag leaf stage and anthesis. Starting date and length of sorghum growth stages are known to vary within a location due to climatic conditions such as daily temperatures. Predictive models could be used to adjust ergot severity data to differentiate genotypes. There is also evidence that relationships between ergot severity and environmental parameters differs for various genotypes which complicates a predictive model. Wang's model in Australia is based on the physiological relationships of sorghum growth and development and ergot infection and climate. For this model, an infection factor and the mean relative humidity at 9:00 hours during flowering were the primary factors influencing ergot. This model cannot be used to predict ergot severity for a particular genotype although it may be used in the relative comparison of ergot incidence in different geographical regions.

A growth model for sorghum (SORKAM) was developed by researchers at Texas A&M and Kansas State to evaluate growth and development of grain sorghum. The model describes the morphological development of a well-fertilized single plant in response to the environment. SORKAM can be used to evaluate sowing date alternatives, plant populations, irrigation scheduling, evaluation of yield variation for years with above and below normal rainfall, and assesses the impact of stress on grain yield.

Grain sorghum received limited attention in Central America in previous years as corn was the crop favored by commercial and subsistent growers. Unfavorable climatic conditions and soils coupled with a 10-fold increase in less than 10 years in the poultry industry has provided an impetus for sorghum production. Sorghum diseases were poorly characterized and the incidence and severity were unknown. Surveys were conducted and the use of genotypes in the ADIN has shed valuable information on sorghum diseases in El Salvador and Nicaragua.

Covered kernel smut is one of the more important diseases of grain sorghum in LDC's. The disease is easily controlled by chemical seed treatments but these chemicals may not be available or the cost may be prohibitive for purchase by farmers. Incorporation of resistant or immune germplasm into acceptable cultivars would partially alleviate concerns about covered kernel smut.

Sooty stripe is a major disease of sorghum in those areas where the crop is primarily grown under limited or no-till cultural practices. Sooty stripe is also important in other countries such as Mali where yield reductions are common (D. T. Rosenow, personal communication).

The causal agent, *Ramulispora sorghi*, has been difficult to increase in culture due to finite growth conditions. Previously in this project, we were able to ascertain growth media and temperature requirements to increase inoculum for a screening protocol. Conditions that enhance disease incidence and severity remain unknown. A misting system to increase relative humidity was installed. The misting system is controlled by leaf moisture sensors that are connected to a controller regulated by a computer software program. It is believed that relative humidity is an important component for disease development. In addition, a dew chamber was purchased to determine the optimum epidemiological parameters for optimum disease severity under growth chamber conditions.

Research Approach and Project Output

Research Approach

The SORKAM model was coupled with the model of McLaren and Flett to evaluate ergot potential on a specific maturity genotype at different planting dates in a specific environment. Thirty years (1970-1999) of consecutive climatic data from weather stations in Concordia, Dodge City, Manhattan, Russell, Topeka and Wichita, Kansas and Grand Island, Nebraska were utilized in the model. These cities are located in regions with extensive acres of sorghum and ergot disease was previously reported.

The weather parameters used were solar radiation, maximum and minimum temperature, moisture, latitude, longitude, and elevation for each location. Three planting days were selected as based on recommendations from Kansas State University for each location and two planting days outside the suggested planting dates (May 1=day 121, and July 1= day 182) were chosen to represent early and late planting date events. All locations shared the same planting dates except for Wichita which has different recommended planting dates.

All inputs including soil type, planting depth, hybrid, plant population, planting depth, row spacing, etc. were similar for the locations. Analysis of variance (ANOVA) and Unequal variance F-test and T-tests were performed for simulated ergot potential responses, using years as replications. Least square means were used to evaluate the effect of planting date on ergot potential. Significant differences were determined at p= 0.05. The two levels of relative humidity (80 and 95%) were used to evaluate the effect of relative humidity on ergot potential. Estimated ergot potential was expressed in terms of percentage of years (30 years) showing severity of ergot greater than 0 and 15% for the planting dates at 80 or 95% relative humidity for each location.

We evaluated various accessions of *Sorghum* spp. and potential grass hosts for their reaction to ergot under greenhouse conditions at Manhattan, KS. Inflorescences were inoculated by spraying a suspension of 2.0 X 10^5 macroconidia/ml at anthesis, panicles were covered with clear plastic bags, and inoculation was repeated after five days. Ergot symptoms were not observed on several accessions from *S. bicolor* ssp. *arundinaceum*, and *S. bicolor* ssp. *drummondii.* Within *S. bicolor* ssp. *arundinaceum*, IS 14257 and IS 14357, representing race *verticilliflorum* and IS 14301 and PI 185574 representing race *arundinaceum* were free of ergot infection. *S. bicolor* spp. d*rummondii* (IS 14131) expressed high levels of resistance to ergot.

IS 14131 and IS 14357 were crossed to A3TX430 to produce male-sterile testcross hybrids to evaluate the physiological basis of resistance in these accessions. Parent lines, male-sterile hybrids, and susceptible lines were evaluated for genetic variability to *C. africana* at the winter nursery in Guayanilla, Puerto Rico and under greenhouse conditions at Manhattan, KS.

Sorghum accessions: F_1 sorghum plants from resistant and susceptible gene combinations were obtained from the sorghum breeding program of Dr. Mitch Tuinstra and are as follows:

TXARG1 = SxS; IS14131 = SxR (resistant); IS8525 = SxR (tolerant).

Inoculation Protocol: F_1 plants were inoculated by dipping panicles into a suspension of *C. africana* conidia and then covered with plastic bags. Four flowers per panicle from each of five plants from each cross were harvested after 6, 13, 18, 24, 36, 48, 72 and 96 hr post inoculation. The collected florets were fixed and stained with cotton blue-lactophenol. Stigmas were sliced with a scalpel to permit observation of single layered stylar hair. Florets were examined with a compound microscope utilizing 25X and 63X objectives.

Ergot model: The model proposed by McLaren for predicting ergot potential under South African conditions is as follows: $Y= (aX_1) + EXP(b X_{2\_} + c X2 + d) + (e^* X_3)$; $Y= (-3.229 \times X1) + EXP(-0.0029 \times X2 \times X2 + 0.0936 \times X2 + 3.061) + (0.379 \times X3)$; Y = expected mean ergot severity in a genetically broad based sorghum population (ergot potential);

X_1= mean minimum temperature (ºC), 23 to 27 days before flowering;

X_2= mean daily maximum temperature (ºC), 1-5 days after flowering;

X_3= 80% or 95% relative humidity (ºC), 1-5 days after flowering.

a, b, c, d ,e= regression coefficients

Research Output

Determination of physiological resistance: Susceptible checks were heavily infected with ergot. The male-sterile crosses were nearly as resistant as the parent lines. Since resistance was expressed in male sterile genetic backgrounds, the mechanism of resistance appears to be physiological in nature. ATX623 had 90% of the florets infected whereas the accessions described as resistant above were nearly free of ergot. Previously, IS 8525 was the only known accession in a male-sterile cross that exhibited tolerance to *C. africana*.

Conidial germination was detected 6 hr after infestation. The 12- hr time frame was similar to the percentage of germinated conidia as observed for 6 hr. More conidia germinated on stigmas of susceptible plants than on resistant ones (Table.1). No conidial germination occurred after 12 hr post inoculation due to extremely high temperatures in the greenhouse (July, 2001). Honeydew was not observed in this experiment.

The experiment was repeated and plants inoculated in April, 2002. Four florets were collected from 6-7 plants of each cross at the same time intervals as above. Environmental conditions in the greenhouse were nearly perfect. Honeydew exuded between the outer glumes eight days after inoculation. Results (Table 1) reveal that lower numbers of conidia germinated on resistant sorghum stigmas than on susceptible plants. Florets are continuing to being analyzed to determine if physiological resistance is the mode of action for sorghum immunity to ergot.

Our ergot predictive model utilizing SORKAM and the ergot model developed for South Africa utilized consecutive climatic data over a 30-year period with five planting dates. Ergot potentials varied among locations mostly due to planting date and/or mean maximum RH during anthesis (Table 2). Most planting dates recommended for each location showed limited or no incidence of ergot based on our model. Late planting dates increased the risk of infection especially in Grand Island, NE. Russell, KS and Grand Island, NE were locations that presented a low risk of ergot within

Table 1. Conidial germination on susceptible, intermediate, and resistant sorghum stigmas 6 hr and 12 hours after inoculation.

Germplasm	No. of conidia examined	No. of germinated conidia	No. of conidia/100,000
6 hr.			
TXARG1	18,960	5	26[1]
IS8525	32,880	1	2
IS14131	47,880	1	3
12 hr			
TXARG1	18,000	6	33[a]
IS8525	23,880	1	2
IS14131	41,040	0	0

Table 2. Maximum ergot potential utilizing 30 years of climatic data for five planting dates

	Maximum Ergot Potential	
	Relative humidity	
Location	80%	95%
Manhattan, KS	1.8 July 1*	7.5 July 1
Concordia, KS	14.6 July 1	20.2 July 1
Grand Island, NE	22.8 July 1	28.5 July 1
Topeka, KS	20.9 July 1	26.6 July 1
Wichita, KS	0	0.7 May 1
Dodge City, KS	14.0 July 1	19.7 July 1
Russell, KS	22.4 June 20	28.0 June 20

*Planting date with highest potential of ergot.

the suggested sorghum planting dates if mean (95%) maximum relative humidity occurred during anthesis. The greatest threat of ergot could occur if sorghum was planted on June 20. Grand Island presented the highest percentage of 30 years (16.67) with risk of ergot incidence if also planted on June 20. Significant differences in ergot potential among RH levels were not observed at four of the locations (Concordia, Russell, Topeka and Wichita, KS) for any of the planting dates. Increasing RH from 80 to 95% at Dodge City and Manhattan, KS and Grand Island, NE significantly increased ergot potentials.

Both panicle and foliar diseases were observed on accessions within the All Disease and Insect Nursery (courtesy of D. T. Rosenow, TAM, Lubbock, TX). For panicle diseases, B35 was particularly susceptible to both *Curvularia* and anthracnose (Table 3). TX 7078, BTX 378, R9188 and R9519 were susceptible to *Curvularia*. Resistant accessions included SC 326, LG 35, 97 BRON 304, B9105 and TX 2911 (Table 3).

Rust was particularly severe in El Salvador and anthracnose was the major foliar disease in Nicaragua (data not shown). Accessions susceptible to rust included SC 630, 87 BH 8606, TX 2880, 95 BRON 151, 88 B 943, and TX 2911 (Table 4). Resistant germplasm included 86 EO 366, 96 GCP OB 124 and BTX 631.

Networking Activities

Workshops

Implemented and conducted a workshop in conjunction with Dr. Pitre (MSU-205) on sorghum pests and diseases in Managua, Nicaragua for approximately 40 attendees from INTA/CINIA, Nicaragua, CENTA, El Salvador and private industry from June 10-14, 2002.

Research Investigator Exchanges

Yanet Gutierrez from UNA, Managua, Nicaragua worked in the lab of L. E. Claflin on a training session from July 29 - August 13, 2002.

L. E. Claflin surveyed sorghum fields and discussed mutual research in El Salvador and Nicaragua in December, 2001.

Various equipment and supplies provided to Reina Guzman in CENTA and Sergio Pichardo in UNA through passthrough funds of KSU-211.

A Zeiss microscope from UNA was carried to the US, cleaned, eyepieces replaced, adjusted and then returned to Nicaragua. Repair of the microscope resulted in a potential savings of $10,000.

Research Information Exchange

Antisera specific to *Xanthomonas campestris* pv. *holcicola* (causal agent of bacterial streak disease of sorghum) was provided to Ranijit Bandyopadhya (ICRISAT) and Jesus Narro (Mexico)

The All Disease and Insect Nursery (ADIN) that was graciously provided by Dr. D. T. Rosenow was planted in two locations in both El Salvador and Nicaragua to determine disease incidence and severity.

Numerous extension publications, compendia, and textbooks were furnished to Reina Guzman and Ing. Sergio Pichardo. In addition, the following speciality equipment

Table 3. Incidence and severity of panicle diseases in the All Disease and Insect Nursery - El Salvador (2001).

	Panicle Diseases				
Accession	Anthracnose	Curvularia	Fusarium	Phoma	Bird damage
B-35	5	5	1	0.8	1
SC 326-6	1.3	1.3	1	1	2
SC 414-12E	2	2.3	1	1.3	1
SC 630-11E(ii)	1	1.7	2	1	1
R 9188	1	4	1	1.4	1
86 EO 366	1	2.7	1	1	1.3
90 EON 328	1.3	1.7	1.3	1	1
90 EON 343	1.1	2	1	1	1
91 BE 7414	1	2.3	1	1	1.3
87 BH 8606-6	1.3	2.7	1.3	1.3	1
88 BE 2668	1	2	1	1	1
94 CW 5045	1	2	1	1	1
96 CA 5986	1	2	1	1.3	1.74
96 CD 635	1	2.3	1	1.3	1
96 CD 677	1.4	2	1	1.3	1
99 BD 3726/98CD187	1.3	1.7	1	1	1.3
99 CA 2244	1	1.7	2	1	1
99 CA 2519	1	2.3	1.3	1	1.7
99 CA 1422	1	1.4	1.3	1	1
99 PR 1159/B LD6	1	2.5	1.5	1	1
LG 70	1	2	1.7	1	1
LG 35	1.3	1.7	1	1.3	1
B8 PR 1011	2.3	2.7	1.3	1.3	1
B8 PR 1059	1	3	1.7	1.7	1
B8 PR 1051	1	2.3	1	1.3	1
98 BRON 125	1	2	1.3	1	1
B8 PR 1013	1	3.7	1	1.3	1
B8 PR 1057	1	1.3	1.7	1	1.3
TX 2880	1	2.5	1.5	1	1
GR 108-90M24	1.3	1.3	1.3	1	1
95 BRON 155	1	1.7	1.3	1	1
95 BRON 151	1	2.3	1.3	1	1
96 GCP OB 124	1	2	1	1	1
96 GCP OB 143	1	1.7	2	1	1.3
96 GCP OB 157	1.3	2	1	1.3	1
96 GCP OB 160	1.7	2.3	1.3	1	1
96 GCP OB 172	1	2.7	1.3	1	1
MB 108 B	1	2	1	1	1.3
97 BRON 179	1	2	1.3	1	1
98 BRON 122	1	1.7	1.7	1	1.7
88 B 928	1	2	1.3	1	2
R 9113	1	2	1.3	1	1
97 BRON 304	1	2	1	1.3	1
B 9104	1	2.3	1.3	1	1
B 9107	1	3	1	1.3	1
87 EO 109	1	1.3	2.3	1	1.7
B 9601	1	2.5	1	1.1	1.5
88 B 943	1	2.7	1	1.3	1
94 B 1055	1.1	3	1	1.8	1
B 9105	1	1.7	1.7	1	1.3
R 9603	1	3.3	1	1.7	1
B 9307	1.4	2	1	1.7	1
R 9120	1	3	2	1.3	1
91 B 2978	1	1.7	1.3	1.3	1.3
TX 2911	1	2	1	1	1
R 9618	1.3	1.7	1	1.3	1.7
R 9519	1	3.7	1	1.3	1
Malisor 84-7	1.7	1.7	1	1.3	1
SRN 39	1	2.3	1	1.3	1
Sureño	1	1.7	1.3	1.3	1.7
TX 2783	1	2.7	1	1.7	1
TX 2767	1	2.7	1.3	1	1
TX 2783	1	2	1	1	1.3
BTX 635	1.3	2	1	1	1
BTX 623	1	2	1	1	2
BTX 631	2	1.7	1.3	1	2.3
TAM 428	1	1.3	2.3	1.3	.2.3
TX 430	1	3	1.3	1.3	1
TX 7078	1.3	4	1.3	2	1
BTX 378	1.3	3.3	1.3	2.3	1

and supplies were purchased with funds from KSU-211 and distributed to the laboratories:

Incubator – Boekel Incubator – No. 133000, Pseudomonas Agar F, Potato Dextrose Broth, Agar, Gram Stain Kit Solutions, Autoclavable Biohazard Bags, Printer HP Office Jet G55xi, Sharp Microwave –Model R209EK, Fisher Latex Examining Gloves, Moldex Respirator Masks, O/F Basal Media, Inoculating Turn Table, Dryslide Oxidase Test, Difco Agar, Gelatin Agar, Nitite Broth, Multicolor Tape Rolls and dispenser, Automatic Slide Dispenser, Lactose Monohydrate, Dextrose, Sorbitol, Mannose, Gram +/- Slides, Nutrient Broth, Yeast Extract, Cellobiose, CD Burner - Plexwriter, Zip Drive – Iomega 250MB

Publications and Presentations.

Abstracts:

Tuinstra, M. R., T. Teferra, L. E. Claflin, R. G. Henzell, N. Seetharama, G. Ejeta, and D. T. Rosenow. 2001. Sorghum Industry Conference, Nashville, TN, February 18-20, 2001.

Ramundo, B. A, M. R. Tuinstra, and L. E. Claflin. 2001. Genetic variability of various plant hosts to *Claviceps africana*. KS-NE Sorghum Conference, Clay Center, NE August 30-31.

Reed, J. D. M. R. Tuinstra, N. W. Ochanda, K. D. Kofoid, and N. W. McLaren. Analysis of ergot resistance in sorghum. 2001. ASA-CSSA-SSSA An. Mtg. Charlotte, NC. Oct 21-25.

Teferra, T. T., M. R. Tuinstra, R. L. Vanderlip, and K. D. Kofoid. 2001. Analysis of genetic diversity for Fusarium stalk rot resistance in sorghum. ASA-CSSA-SSSA An. Mtg. Charlotte, NC Oct 21-25.

Journal Articles

Claflin, L. E., M. R. Tuinstra, and B. A. Ramundo. 2001. Ergot: A new disease of sorghum in the Western Hemisphere, pp. 114-127. *In* Proc. Am Seed Trade Assoc. Mtg., Chicago, Il, December 5-8, 2000.

Tuinstra, M. R., T. Teferra, L. E. Claflin, R. G. Henzell, A. Borrell, N. Seetharma, G. Ejeta and D. T. Rosenow. 2001. Root and Stalk Rot Resistance in Sorghum. Proc. 22nd Biennial Grain Sorghum Research Utilization Conference. Nashville, TN, Feb 18-20, 2001. Pgs 32-34.

Presentations

Claflin, L. E. 2001. Pokkah boeng disease of corn and sorghum. Universidad Nacional Agraria, Managua, Nicaragua, Nov 27.

Claflin, L. E. 2001. Pokkah boeng disease of corn and sorghum. Centro Nacional de Technologia (CENTA), La Libertad, El Salvador, Nov. 29 .

Claflin, L. E. 2001. Pokkah boeng disease of corn and sorghum. Pioneer Hi-Bred Int (and others), Guadalajara, Mexico, Dec. 3.

Miscellaneous Publications

Claflin, L. E. 2001. Agroecology and biotechnology of fungal pathogens of sorghum and millet. Pp. 11-17 in INTSORMIL Ann. Repts., A Technical Res. Rept. of the Grain Sorghum/Pearl Millet Collaborative Res. Support Prog. (CRSP), University of Nebraska, Lincoln.

Table 4. Incidence and severity of foliar diseases of sorghum accessions in the All Disease and Insect Nursery - El Salvador (2001)

Accession	Foliar Diseases Zonate	Leaf Blight	Grey Leaf	Rust	Ergot	Anthracnose	Bacteria
B-35	1	0.8	3	2.3	3	5	1
SC 326-6	1.3	1.3	1.3	1.7	1	2	1
SC 414-12E	1.7	1.3	2	2.3	2	1.7	1
SC 630-11E(II)	1	1.8	1	3.4	1	0.8	1
R 9188	1	0.8	1	3	1.5	0.8	1
86 EO 366	1	2.3	1	1	2	1.7	1
90 EON 328	1	2.3	1	2	1	1	1.3
90 EON 343	1	1.8	1	2	1	1.3	1
91 BE 7414	1	1.7	1	2.3	1	1.3	1
87 BH 8606-6	1	1.3	1.3	3.7	1	1	1
88 BE 2668	1	1.3	1.3	2.3	1	1.7	1.3
94 CW 5045	1.5	1.5	1	2.6	1	1.1	1
96 CA 5986	1	2	1.3	1.3	1	1.3	1
96 CD 635	1.3	2.3	1	2	1	1.3	1
96 CD 677	1.3	1.7	1.3	2.3	1.3	1.7	1
99 BD 3726/98CD187	1	1.3	1	3	1	1	1
99 CA 2244	1	2.3	1.3	1.7	1	1	1
99 CA 2519	1	1.7	1	1.3	1	1.7	1
99 CA 1422	1	1.3	2.3	1.7	1	1.7	1
99 PR 1159/B LD6	1	2.1	1	1.6	1	2.1	1
LG 70	1.7	1.3	1.32	3	1.7	1.3	1
LG 35	1	1.3	1	1.3	1	4	1
B8 PR 1011	1.3	1.3	1	2.7	1	2.7	1
B8 PR 1059	1	2	1.3	2	1	2	1
B8 PR 1051	1	1.7	1	1.3	1	2.3	1
98 BRON 125	1	2	1.3	1.3	1	1.7	1
B8 PR 1013	1.3	1	1.3	2.3	1	1.7	1
B8 PR 1057	1	1	1.3	2	1	2.7	1
GR 108-90M24	1	1.3	1.7	2.3	2.3	2.3	1
95 BRON 155	1	1	1.3	1.7	1.3	2.3	1
95 BRON 151	1	1.3	1	4.7	1	1.7	1
96 GCP OB 124	1	2.3	1	1	1	1.3	1
96 GCP OB 143	1	1.7	1	2	1	1	1
96 GCP OB 157	1	1.7	1.3	2	1.3	3.3	1
96 GCP OB 160	1	1	1	1.7	1.3	2.7	1
96 GCP OB 172	1	1	1	1.3	2	4	1
MB 108 B	1	2	2	2.7	1	2	1
97 BRON 179	1	1	1	2.3	1	3	1
98 BRON 122	1.3	1.7	1.3	2.3	1.3	1.3	1
88 B 928	1	1.7	1	2.3	1.3	2	1
R 9113	1.3	2.3	1	2	1	1.3	1
97 BRON 304	1.7	2.3	2	2.7	1	1	1
B 9104	1	1.3	2	1.7	1	1	1
B 9107	1	1	1	2.7	1.3	3.7	1
87 EO 109	1	1.7	1	3.3	1	1.3	1
B 9601	1.5	1.1	1	1.9	1	3.1	1
88 B 943	1	1.3	1	4	1.3	2.3	1
94 B 1055	1	1.8	1	2.3	1	2	1
B 9105	1	1	1.7	2.7	1	3	1
R 9603	1.3	1.3	1	2.3	1	1.7	1
B 9307	1	2	1	2	1	1.7	1
R 9120	1	1.3	1	2.3	1	1.7	1
91 B 2978	1.7	1	1.3	2	1	1.3	1
TX 2911	1	1	1	4	1	1	1
R 9618	1	1.7	1	2	1	1	1
R 9519	1	1.7	1	3	1	2.3	1
Malisor 84-7	1.3	2	1.7	1.7	1	1.3	1
SRN 39	1	1.3	1	3.3	1	1	1
Sureño	1	2	1	2.3	1	1.3	1
TX 2783	1	1.3	1	3.3	1	1	1
TX 2767	1.3	1.7	1.3	3.3	1	2	1
TX 2783	1.7	1.3	1.7	3	1.7	2	1
BTX 635	1	1.7	1	1.7	1.3	1.3	1
BTX 623	1.3	1	1.7	1.7	1	2	1
BTX 631	1	2	1	1	1	1	1
TAM 428	1.3	1.7	1.3	2	1	2	1.3
TX 430	1.3	1	1	3	1.7	1	1
TX 7078	1	1	1.1	3	1	1	1
BTX 378	1.3	2	1	3.3	1	1.3	1
TX 2880	1	1.1	1	4.1	1	2.1	1

Rating scale: 1= trace - 2%; 2 = 2 - 10%; 3 = 11- 25%; 4 = 26 - 50; 5 = 51 - 75%; 6 = death.

Enhancing the Utilization of Grain Sorghum and Pearl Millet through the Improvement of Grain Quality Via Genetic and Nutritional Research

Project KSU-220

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Summary

Natural tolerance to heat and drought permit sorghum to be grown in areas unsuited for production of other cereal crops. Past breeding efforts have significantly enhanced yield potential, but little attention has been focused on grain quality. Grain development under heat and drought stress results in variable seed size and composition whereas development under high rainfall and humidity favors grain mold and weathering. Both conditions lead to lower food and feed value.

The marketing and utilization of sorghum grain often has been limited by poor grain quality. Grain mold is a common problem because sorghum kernels are exposed to the environment as they mature. However, even in the absence of contaminating fungi, sorghum grain typically has lower digestibility and metabolizable energy values when compared to other cereals. Numerous researchers have reported differences in growth performance of poultry and swine when fed grain from different varieties of sorghum; however, little information is available about inheritance of food and feed

quality components and their associations with digestibility and nutritional quality. Research and germplasm development activities in KSU-220 attempt to address these questions and problems.

Our research efforts are focused on identification and characterization of germplasm sources that have improved grain quality and nutritional value characteristics. Breeding projects to assemble these genes into improved cultivars should proceed rapidly with the aid of marker-assisted selection and with performance tests made in multiple environments. The results from these studies will contribute to the development of value-enhanced sorghum and millet grains and the transfer of animal feeding technologies will promote the development of new entrepreneurial opportunities for production of meat and other animal products in Africa and Central America.

In the past year, we initiated several studies to identify and characterize sources of grain and nutritional quality. We have also initiated theoretical studies to evaluate the most effective strategies for implementing marker-assisted selection in sorghum crop improvement. Given the recent implementation of this project, most of these studies were only just initiated; however, we will be providing preliminary results from a poultry feeding trial to evaluate nutritional characteristics of sorghum hybrids with variable seed size.

Objectives, Production and Utilization Constraints

Objectives

Research

- Study the inheritance of seed size and feed quality components in sorghum.
- Determine the metabolizable energy content of sorghum hybrids differing in seed size versus corn in poultry rations.
- Identify, clone, and map genes for grain mold resistance, anthracnose resistance, and improved nutritional characteristics.

Germplasm Development

- Develop sorghum varieties and hybrids with improved yield potential and food quality characteristics.
- Develop recombinant inbred (RI) sorghum mapping populations to identify markers for grain mold resistance, anthracnose resistance, and improved nutritional characteristics.
- Evaluate tan-plant food sorghum hybrids for differences in grain quality and food processing characteristics.
- Evaluate the feasibility of marker-assisted selection for grain mold resistance.

Training, Networking, and Institutional Development

- Identify graduate students from Central America and Africa through the aid of collaborators.
- Establish formal and working collaborations and plans for work in Central America and Africa.

Constraints

Sorghum and millet production around the world is constrained by the lack of high-yielding cultivars with superior food and feed quality characteristics. This interdisciplinary research project attempts to address this problem through research to develop a better understanding of the genetic traits and physical properties that contribute to grain and nutritional quality and through crop improvement efforts via biotechnology and traditional plant breeding approaches.

Breeding efforts to directly address nutritional quality of grain sorghum have been slowed by the lack of routine screening procedures for this trait. Accurate methods for determination of chemical composition are well documented (AOAC, 1990), but tend to be complicated and are not acceptable predictors of nutrient bioavailability. Research strategies must be developed to measure food or feed efficiency traits. Components of feed quality are frequently defined in terms of animal performance such as weight gain per unit of grain fed or in terms of metabolizable energy per unit of grain. These traits can be measured in animal feeding trials, but these experiments are costly and not amenable to high-throughput testing as required in a plant breeding program. Therefore, rapid and less hazardous screening methods need to be developed and applied to prediction of nutritional characteristics for grain sorghum and millet.

Genes for grain and nutritional quality can be identified and tagged with DNA-based markers to facilitate crop improvement. Breeding projects to assemble these genes into improved cultivars should proceed rapidly with the aid of marker-assisted selection and with performance tests made in multiple environments. The combined expertise of the team assembled for this proposal will permit identification, verification, and implementation of genes that contribute to various aspects of grain quality.

Research Approach and Project Output

Analysis of feed quality and metabolizable energy content of sorghum and corn hybrids.

Research Methods

Simultaneous genetic improvement for grain size and feed quality requires evaluation of seed weight and the major characteristics of feed: contents of protein, fat, and starch and digestibility. Several studies have investigated the chemical composition of grain sorghum; however, little information is available about inheritance of that composition and digestibility and their associations with feed quality. Knowledge of genetic variability for feed quality characteristics, digestibility, seed weight, and their associations is desirable for designing optimal breeding strategies to improve feed quality.

Germplasm sources with a dominant mode of inheritance for seed size have been identified. In our research, one of the best germplasm sources for increased seed size and yield potential was the breeding line KS115. Given the dominant pattern of inheritance for these traits in this line, this germplasm source should be extremely useful in development of sorghum varieties and hybrids with increased seed size and crude protein content and better protein quality. However, feeding trials were needed to measure the impact of these traits on animal performance characteristics and metabolizable energy (ME) content.

Poultry feeding trials are currently being conducted to evaluate the potential effect of seed size on feed efficiency and ME content of sorghum. Eight sorghum hybrids differing in seed size and feed quality characteristics were grown at two locations in Kansas in 2000. Bulk grain samples (20 kg) for each hybrid were harvested for determination of feed quality. A bulk sample of corn produced at each location was also obtained for comparison with the sorghum samples. Differences in feed quality characteristics among hybrids were determined using a randomized complete block design with environments as blocks.

Newly hatched chicks were obtained for feeding trials. The experiment was conducted using a randomized complete block design with six chicks per cage and six cages per feed treatment. Diets were prepared according to NRC guidelines using hammer milled grain sample (2.4 mm). The chicks were fed a common diet for 14 days and were then changed to diets with the various grain treatments for seven days. Feed and water were consumed on an *ad libitum* basis. Chicks were allowed to adjust to the experimental diets for five days then fecal samples were collected for two days. The excreta and diets were dried and analyzed for gross energy, nitrogen, and chromium to allow calculation of ME for the test ingredients. Differences in weight gain and gain/feed were measured to evaluate growth performance.

Research Findings

When combined with improved yield potential, increased seed size and uniformity should enhance utilization attributes of sorghum grain. More consistent seed size should improve the physical and mechanical handling of grain during processing and may also improve flour yield for food-grade sorghums. Sorghum varieties with large grain also tend to be preferred for food use in many developing countries where sorghum is used for human consumption.

Although multi-year studies will ultimately be required to determine the effect of seed weight on nutritional value, differences in feed and nutritional quality characteristics of corn and sorghum hybrids were detected in grain samples produced in 2000 (Table 1). In general, the larger seeded hybrids developed using KS115 were generally higher in crude protein and fat as compared to normal sorghum hybrids. Large differences in metabolizable energy content were also noted among grain samples (Table 2). Again, hybrids produced using KS115 were generally higher in metabolizable energy content than conventional sorghum hybrids. Surprising, SA3042 × KS115 was significantly higher in metabolizable energy content than the corn samples in the combined analysis. Although preliminary, these results indicate great promise for improving metabolizable energy content of sorghum by integrating KS115-type grain characteristics into improved genetic backgrounds.

Table 1. Analysis of feed quality characteristics of sorghum and corn hybrids grown at two locations in Kansas in 2000.

Pedigree	Seed weight g 100 seed $^{-1}$	Crude protein %	Crude fat %
Wheatland × KS115	4.04	12.56	4.01
SA3042 × KS115	3.03	12.83	3.70
Wheatland × Eastin-1	2.81	12.62	3.55
SA3042 × Eastin-1	2.68	12.46	3.43
Wheatland × Tx2737	2.26	11.53	3.60
SA 3042 × Tx2737	3.01	11.67	3.46
Wheatland × Tx 435	2.53	11.24	3.13
SA3042 × Tx 435	2.49	12.19	3.47
Bulk Corn		10.27	3.82
LSD (0.050)	1.30	1.47	0.42

Table 2. Metabolizable energy content of sorghum and corn grain samples produced at Manhattan and Ottawa, Kansas in 2000.

	Metabolizable energy		
Hybrid	Manhattan	Ottawa	Combined
	- - - - - - - - - -	kcal	- - - - - - - - - -
Wheatland × KS115	3.48	3.52	3.50
SA3042 × KS115	3.74	3.63	3.668
Wheatland × Eastin-1	3.37	3.42	3.39
SA3042 × Eastin-1	3.34	3.43	3.38
Wheatland × Tx2737	3.33	3.28	3.30
SA 3042 × Tx2737	3.59	3.45	3.52
Wheatland × Tx 435	3.27	3.12	3.20
SA3042 × Tx 435	3.61	3.15	3.38
Bulk Corn	3.49	3.33	3.41
LSD (0.050)	0.26	0.26	0.27

Networking Activities

Workshops /Conferences

Drs. Rooney and Hancock attended INTSORMIL Central American research planning and coordination meeting in Managua, Nicaragua, February 26-28, 2002. During this meeting, work plans were established with Ing. Rene Clara, Hector Deras and Rafael Obando.

Dr. Tuinstra attended the Sorghum Industry Conference and the Sorghum Germplasm Committee Meeting in San Francisco, CA, February 18-20, 2002.

Germplasm and Research Information Exchange

Germplasm was sent to collaborating scientists in El Salvador, and Zambia for evaluation in these locations during the 2002 growing season.

Two hybrid sorghum trials were developed and distributed to cooperators in 2002. The IFSAT (International Food Sorghum Adaptation Test) is compiled of tan plant sorghum hybrids predominantly from the TAM220C, TAM222 and TAM223 for evaluation worldwide. The TPHT (Tan Plant Hybrid Trial) is a cooperative test between Texas A&M and Kansas State University, funded by PROFIT and the National Grain Sorghum Producers to evaluate commercial tan plant hybrids for agronomic and grain quality in U.S. production systems.

Dr. Rooney released two sets of sorghum germplasm (Tx2912-2920 and Tx2921-Tx2928) in February 2002. These germplasms were made available to sorghum improvement programs throughout the world. In addition, standard hybrid tests of food quality (IFSAT) hybrids were prepared and distributed to cooperators in the U.S., Mexico, Central America and Southern Africa.

Publications and Presentations

Journal Articles

Hicks, C., M.R. Tuinstra, J. Pedersen, F.E. Dowell, and K.D. Kofoid. 2002. Genetic analysis of feed quality and seed size in sorghum inbred lines and hybrids using analytical methods and NIRS. Euphytica (In Press).

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Islam-Faridi, M.N., K. L. Childs, P. E. Klein, G. Hodnett, M. A. Menz, . R. Klein, W. L. Rooney, J. E. Mullet, D. M. Stelly and H. J. Price. 2001. A Molecular Cytogenetics Map of Sorghum Chromosome *1*: FISH analysis with Mapped BACs. Genetics.

Dahlberg, J.A., R. Bandyopadhyay, W.L Rooney, G.N. Odvody, and P. Madera-Torres. 2001. Evaluation of sorghum germplasm used in U.S. breeding programmes for sources of sugary disease resistance. Plant Pathology 50:681-689.

Klein, R.R., R. Rodriguez-Herrera, J.A. Scheulter, P.E. Klein, Z.H. Yu, and W.L. Rooney. 2001. Identification of genomic regions that affect grain mold incidence and other traits of agronomic importance in sorghum. Theor. Appl. Genet. 102:307-309.

Hicks, C., S.R. Bean, G.L. Lookheart, J.F. Pedersen, K.D. Kofoid, and M.R. Tuinstra. 2001. Genetic analysis of kafirins and their phenotypic correlations with feed quality traits, in vitro digestibility, and seed weight in grain sorghum. Cereal Chemistry 78:412-416.

Tuinstra, M.R., G.L. Liang, C. Hicks, K.D. Kofoid, and R.L. Vanderlip. 2001. Registration of KS 115 sorghum. Crop Science 41: 932-933.

Books, Book Chapters, and/or Proceedings

Tuinstra, M.R., T.D. Kriegshauser, R.L. Vanderlip, K.D. Kofoid, and J.D. Hancock. 2001. Can long grain-fill duration improve yield potential and grain quality of sorghum? Pp. 185-195. In Proceedings of the 56th Corn and Sorghum Research Conference, 2001. American Seed Trade Association. Chicago, IL, Dec. 5-7, 2001. Alexandria, VA. USA.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-205
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Summary

MSU-205 sorghum plant protection research and institution building activities in Honduras were de-emphasized in 2001. Entomological research was expanded in Nicaragua and El Salvador, with emphasis on insect pest constraints to sorghum production in improved cropping systems on large agricultural farms on the Pacific coastal plain, unlike the activities of the past 15 years when this project worked with low input, subsistence farming systems in Honduras. Collaborative research activities in Nicaragua with the Instituto Nicaraguense de Technologia (INTA), the Universidad Nacional Agraria (UNA), and the Universidad Autonoma de Nicaragua (UNAN) in Nicaragua, and the Centro de Technologia de Agricola (CENTA) in El Salvador have included investigations on insect biology, behavior, ecology and population dynamics of the sorghum midge and fall armyworm, the two principal insect pests on sorghum in this region of Central America. Information from these investigations is used in developing cultural, biological and chemical control tactics for implementation in insect pest management programs for specific pests or complex of pests. Crop protection information was published for distribution into farm communities in Honduras, as the result of research on a complex of insect pests that limits sorghum production in this country. Similar popular articles have been published for farmer utilization in the application of sorghum midge pest management in Nicaragua and El Salvador. Complementary research on insect pest behavior and damage to sorghum is in progress in the United States for improving sorghum midge and fall armyworm pest management strategies. Collaborative participation in this research with scientists at INTA, UNA, UNAN, CENTA and the Nicaraguan National Sorghum Producers Association (ANPROSOR) has been fruitful in developing greater research capacity and furthering institution building activities in this ecogeographic zone. Graduate student education and professional workshops have increased agricultural capabilities of professionals in this region of Central America. The MSU-205 principal investigator will continue to support graduate student education, to conduct sorghum research in Central America and the United States, to collaborate with scientists in governmental organizations and agricultural universities, and to work with non-governmental organizations to develop improved insect pest management practices for sorghum production.

Objectives, Production and Utilization Constraints

Honduras

- Conduct on-farm survey to determine farmer acceptance and utilization of improved sorghum production and insect pest management practices in traditional and improved intercropped sorghum production systems in hillside and coastal plain fields in southern Honduras.

- Complete graduate student research and academic program for Master of Science degree in entomology at Mississippi State University.

- Prepare manuscripts for publication in scientific journals.

Nicaragua

- Complete graduate student research and academic program for Master of Science degree in entomology at Mississippi State University.
- Prepare manuscripts for publication in scientific journals and popular article for distribution into farm communities.
- Meet with Central America collaborator scientists in INTA, UNA UNAN and ANPROSOR to develop collaborative sorghum crop protection research plans for 2002.
- Complete first year of research and academic programs for MSU-205 PhD student.

El Salvador

- Collaborate with scientists in CENTA to evaluate insecticides and application procedures for fall armyworm management and evaluate sorghums for resistance to this lepidopterous pest.

United States

- Conduct experiments to evaluate the effectiveness and economical benefit of insecticide spray programs and refine the economic thresholds for fall armyworm and sorghum midge on sorghum.

Research Approach and Project Output

Honduras

Research in Honduras for the past 23 years emphasized biology, ecology behavior, population dynamics and pest control tactics for soil insects, foliage feeders and stem borers that were identified as the principal insect pest constraints to intercropped sorghum and maize production on subsistence farms in southern Honduras. Information obtained was incorporated into insect pest management programs appropriate for this region. The results of collaborative research with scientists at the Panamerican School of Agriculture was published in 1999 by Zamorano Academic Press in a popular article, "La Langosta del Sorgo y el Maiz". This publication was distributed into farm communities to provide recommendations to farmers for management of the complex of insects that is devastating to these crops annually. Cultural, chemical and biological control practices have been identified for use in integrated insect pest management programs for the principal pests on these grain crops. The benefits of this information have been reported in previous INTSORMIL annual reports and numerous scientific journal papers. For example, an economic evaluation of integrated insect pest management tactics in intercropped sorghum and maize production systems in southern Honduras indicated that sorghum production was increased by 20% and maize by 35% at the farm level. These increases could return $2.9 million a year to production of these crops in this area when market prices are high.

The on-farm survey conducted in June 2002 in southern Honduras included subsistence farmers in hillside and coastal plain sorghum production systems. The survey included farmers that cooperated with MSU-205, as well as several that were not cooperators. A survey instrument was prepared and administered in Spanish in person by the MSU-205 graduate student. Farmers were selected at random for interviews. The survey was particularly interested in information on changes in crop production practices used by farmers in this region, as well as the extent of technologies that were provided to the farmers by agricultural professionals in the region.

Several things became apparent after only a limited number of interviews. The subsistence farmers in this region have little contact with agricultural professionals, possibly only once a year or even less; the small amount of chemicals used are generally given to them by agriculture related private organizations, but occasionally they have to purchase the materials if they use the materials over time and do not use improved sorghums developed for this region; and they have poor access to crop production literature or exposure to agricultural professionals at meetings, either on the farm or in a nearby community.

There appears to be little currently available insect pest management and crop production technology transferred from professional crop production specialists to subsistence farmers in this region of Honduras. Several farmers indicated that their source of certain improved crop production technology was obtained from individuals in the MSU-205 project. It was apparent from this interview that an educational program is needed and that it must be conducted at a level of educational understanding for the illiterate farmers in this region. Sorghums have been developed, agronomic crop production practices have been identified and insect pest management programs have been designed for improved sorghum yield in this region of Honduras. These technologies are available to crop production specialists, but they are not transferred to the farmers.

Nicaragua

MSU-205 initiated research activities in Nicaragua in 1999, after initially developing collaborative relationships with scientists at INTA in Managua in 1998. Unlike research activities in Honduras during the past 15 years in subsistence farming situations, entomological research in Nicaragua emphasized insect pest constraints to sorghum production in large, improved technology systems on the Pacific coastal plain. The principal insect pest constraints to sorghum production on the coastal plain are recognized to be sorghum midge, fall armyworm and chinch bug, the midge being most destructive. Research was conducted to determine seasonal occurrence of sorghum midge on host plants and oviposition behavior on specific hosts. Tactics for management of the midge were evaluated and included planting date, crop variety and insecticide efficacy. A Master of Science thesis was completed and one manuscript representing this research was prepared for publication in the international journal, "Tropical Agriculture". This paper involved management of the sorghum midge on sorghum on the coastal plain of Nicaragua. A second journal paper considered the occurrence of sorghum midge on sorghum during the second crop-growing season on the Pacific coastal plain of Nicaragua is to be published in "LaCalera" the scientific journal of the National Agricultural University of Nicaragua. A popular article, "La Mosquita De La Panoja Del Sorgo", was published by INTA and prepared for distribution into farm communities in 2002. The information in this publication will assist farmers in sorghum midge pest management.

The student that completed the Master of Science degree in entomology is continuing entomology studies for a Ph.D. degree at Mississippi State University. This research emphasizes economic thresholds and evaluations of fall armyworm and sorghum midge management practices in monoculture sorghum in the United States. These studies were initiated in 2001.

The MSU-205 PI and MSU-205 Ph.D. graduate student participated in the Central America Sorghum Workshop in Managua in February 2002. Collaborative crop protection research was discussed and plans were made for the 2002 growing season. Particular emphasis was given to developing plans for collaborative, multidisciplinary, on-farm crop protection investigations with MSU-205, INTA, UNA and ANPROSOR collaborating. A work plan has been prepared and will be implemented in 2002.

The MSU-205 PI (Pitre) and KS-210B PI Claflin) conducted a five-day sorghum plant protection workshop in Managua, June 10-14, 2002. The workshop was sponsored by INTA and UNA and was attended by 38 agricultural professionals from INTA, UNA and ANPROSOR (in Nicaragua) and CENTA (in El Salvador). Technical presentations included entomology and plant pathology pest management principles, pest management tactics and strategies, defining integrated pest management programs and specific insect and disease agent pest constraints to sorghum production in Nicaragua and the region and related pest management programs. Participants were presented a workshop manual that included pictures of the insect pests and associated plant damage to be considered in the entomological presentations. Field trips were taken to observe insects and related plant damage, as well as plant diseases on sorghum.

El Salvador

Entomological research with scientists in CENTA was planned and coordinated for the 2001 sorghum growing season in El Salvador, when the MSU-205 PI visited CENTA in November, 2000. Insects of greatest interest and thought to be the most damaging to sorghum crops in El Salvador include the complex of soil inhabiting insects, and defoliators (particularly fall armyworm). The objectives of research for 2001 involved identification of the complex of soil insect pests and determining the extent of damage and economic significance of these insects on sorghum. This objective included elucidation of the occurrence and aspects of population dynamics of these pests. Plans were made to obtain this information from sampling programs in different crop agroecosystems. A second planned objective involved the principal insect defoliator, the fall armyworm. Observations on populations of this caterpillar on and damage to sorghum in the All Disease and Insect Nursery (ADIN) was made during the 2001 crop growing season. This was coordinated with collaborating sorghum breeder and plant pathologists in CENTA and Kansas State University (KSU-210B), respectively.

Insecticide evaluations for efficacy on fall armyworm larvae on sorghum four days after application indicated that the chiten inhibitors, Lufenuron and tefubenzuron, provided the greatest mortality (92%), Lorsban provided 63% mortality, whereas nuclear polyhedrosis virus and a fungus, *Bauveria bassiana*, provided low mortality (< 5%), with the botanical insecticide Neem providing 17% mortality. Mortality of fall armyworm larvae in plots treated with Lorsban insecticide at two rates in two different volumes of water was significantly influenced by two applications compared with one application, but was not significantly influenced by volume of water. Insecticide treatment plots yielded more than the untreated plots. Infestations of fall armyworm larvae on sorghum treated with Lorsban was lower with each additional spray application, but yield of plots was not significantly different among treatments; all insecticide treatments had higher yield than the untreated. These results indicate that sorghum plants damaged by fall armyworm in early vegetative stages can compensate for this damage during later stages of plant development. This further indicates that insecticides should be used with complete knowledge of the stage of plant development at the time of fall armyworm infestation and potential for this pest to cause irreversible feeding damage to the developing plants. The infestation level at critical times during sorghum development should be given particular attention in recommending fall armyworm control measures using recommended insecticides. Additional research is needed to refine the recommendations for fall armyworm pest management on sorghum during different phenological stages of the crop.

Sorghums were evaluated in the "All Disease and Insect Nursery" (ADIN) in collaboration with entomologist and plant pathologist at CENTA and KSU-210B PI (Claflin). No significant differences in damage were recorded for varieties tested, although several varieties had lower damage ratings than other varieties; these varieties are recommended for the breeding program. Yields were similar for all varieties except a local variety, which had lower yield.

These and similar studies will be conducted in 2002. Particular emphasis will be given to studies to determine economic damage and economic threshold levels for fall armyworm on sorghum in different stages of plant development. Similar studies will be conducted in the United States (Mississippi).

United States

The economic threshold for caterpillar pests on whorl stage sorghum and sorghum midge on panicles is not clearly identified for sorghum in different growth stages. Preliminary studies were conducted in 2001 with fall armyworm to determine infestation levels suitable for artificial infestations, survival of fall armyworm larvae in three stages of development at infestation and over time after infestation, time of day most suitable for infestation, and other infestation procedures. This information is being used in 2002 to observe fall armyworm larval behavior and to refine economic threshold levels using two strategies, one involving number of insects per plant and the other percentage of plants infested. Yield data will be recorded for treatments. This research will be duplicated by CENTA in El Salvador. Information from these studies can improve the application of pest management practices for fall armyworm on sorghum.

Replicated field tests were conducted in 2001 to determine the optimum procedures for infesting sorghum in the whorl stage with fall armyworm larvae. Mechanical infestation using the “bazooka application” provided satisfactory infestation levels when first, second or third instar larvae were used. Infestation levels were compared to determine survival of larvae over time. Results indicated that regardless of the number of larvae placed on plants in the whorl stage generally only one insect was present on each plant when larvae reached the last instar. Time of day when plants were infested did not appear to influence the success of the infestation method.

Economic threshold studies will be conducted with sorghum midge on sorghum in 2002 and 2003.

Networking Activities

Collaborator scientists and administrators at INTA in Nicaragua expressed interest in supporting a sorghum crop protection workshop emphasizing pest management. This workshop was successfully conducted in June 2002 and included aspects of integrated insect and plant disease management. MSU-205 and KS-210B PI’s were presenters. The workshop was successful because of detail coordination by scientists and administrators at INTA and UNA.

Research investigator exchanges involved shipment of supplies and small equipment for research purposes.

Networking with ANPROSOR provides opportunities to conduct on-farm research with cooperation from many farmers associated with this national sorghum producers association.

The popular articles on sorghum midge in Nicaragua, prepared by INTSORMIL MSU-205 and INTA, provides information for farmers to manage this insect pest on sorghum to improve yield. This publication is distributed by INTA into farm communities with assistance from local agricultural professionals.

Publications and Presentations

Journal Articles

Vergara, O.R. and H.N. Pitre. 2001. Planting data, weed management and insecticide application practices for control of lepidopterous pests in intercropped sorghum and maize in southern Honduras. Trop. Agric. 78: 182-189

Vergara, O.R., H. Pitre and D. Parvin. 2001. Economic evaluation of lepidopterous pests in intercropped sorghum and maize in southern Honduras. Trop. Agric. 78: 190-199.

Dissertations and Theses

Carrillo, Mario. 2001. Insect populations and pest management strategies in traditional and improved sorghum and maize production systems in foothill and coastal plain fields in southern Honduras. M.S. thesis. Mississippi State University 71 pp.

Miscellaneous Publications

Presentations

Pitre, H.N. 2002. Insect pests on sorghum and related crop management practices. Presentation at Central America Sorghum Workshop. Managua, Nicaragua. February.

Pitre, H.N. 2000. Insect pests and pest management practices for sorghum in Nicaragua and other areas in the Central America zone. Sorghum Crop Protection Workshop, Managua, Nicaragua. June. (6 presentations)

Striga Biotechnology Development and Technology Transfer

Project PRF-213

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Dr. Hamis Sadaan, Sorghum Breeder, Tanzania
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Summary

Witchweeds (*Striga* spp.) are obligate parasitic weeds of significant economic importance. Control methods available to date have been costly and beyond the means of farmers in developing countries. While combining several control measures may be necessary for eradication of *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance. Our goal is to exploit the unique life cycle and parasitic traits of *Striga* especially the chemical signals required for germination, differentiation, and establishment.

In Year 23, we summarize part of a Ph.D. research by a former student, Abdalla Mohamed of Sudan, who has discovered that certain sorghum genotypes are resistant to *Striga* because of a unique mechanism where they show necrotic tissue at the point of parasitic attachment thereby discouraging normal development of the parasite. This expression called a hypersensitive response is typical in many pathogens where further development and expansion of pathogenic infection is curtailed by the defense response caused by necrosis developing at the site of infection. We developed new laboratory assays that target the disruption of a particular signal exchange or that detect a precise defense response at a given point in the life cycle of the parasite to define and characterize mechanisms of resistance. The major premise of our research thrust in *Striga* is based on the fact that field *Striga* resistance is quantitatively inherited and is influenced by confounding environmental factors, and is therefore difficult to manipulate. On the other hand, individual interactions between host and parasite in the early stages of the infection process appear to be simply inherited. Characterization of these more qualitative interactions between host and parasite, allows us to dissect the complex trait of *Striga* resistance into more manageable components based on the nature or action of signals exchanged between the parasite and its hosts. As a result, selection efforts directed to pooling these variations of signal exchanges between host and parasite may lead to a more durable *Striga* resistance.

Objectives, Production and Utilization Constraints

The overall objectives of our research are to further our understanding of the biological interactions between *Striga* and its hosts, and to devise control strategies based on host resistance. In addressing our goal of developing sorghum cultivars that are resistant to *Striga*, we emphasize the vital roles of the multiple signals exchanged between the parasite and its hosts, which coordinate their life cycles. To develop control strategies based on host-plant resistance, we employ integrated biotechnological approaches combining biochemistry, tissue culture, plant genetics and breeding, and molecular biology.

Striga spp. is economically important parasites of sorghum, millets and other cereals in tropical Africa and Asia. Yield losses of sorghum due to *Striga* infestation, coupled with poor soil fertility, low rainfall, and lack of production inputs, all contribute to survival difficulties for subsistence farmers. Eradication of *Striga* has been difficult to the unique adaptation of *Striga* to its environment and the complexity of the host-parasite relationship. Suggested control measures including mechanical or chemical weeding, soil fumigation, nitrogen fertilization, have been costly and beyond the means of poor subsistence farmers. Host plant resistance is probably the most feasible and potentially durable method for the control of *Striga*. Host resistance involves both physiological and physical mechanisms. Our goal is to unravel host resistance by reducing it to components based on the signals exchanged and disrupt their interactions at each stage of the *Striga* life cycle. The specific objective of our collaborative research project are as follows:

- Develop effective assays for resistance-conferring traits and screen breeding materials assembled in our *Striga* research program for these traits.
- Elucidate basic mechanisms for *Striga* resistance in crop plants.
- Combine genes for different mechanisms of resistance, using different biotechnological approaches, into elite widely adapted cultivars.
- Test, demonstrate, and distribute (in cooperation with various public, private, and NGOs) elite *Striga* resistant cultivars to farmers and farm communities in *Striga* endemic areas.
- Develop integrated *Striga* control strategies, with our LDC partners, to achieve a more effective control than is presently available.
- Assess (both *ex ante* and *ex post*) of the adaptation and use of these control strategies, in cooperation with collaborating agricultural economists.
- Train LDC collaborators in research methods, breeding approaches, and use of integrated *Striga* control methods and approaches.

Research Approach and Project Output

Research Methods

Field evaluation of crops for *Striga* resistance has been slow and difficult, with only modest success. Our research addresses the *Striga* problem as a series of interactions between the parasite and its hosts, with potential for intervention. We recognize that successful *Striga* parasitism is dependent upon a series of chemical signals produced by its host.

The working hypothesis is that an intricate relationship between the parasite and its hosts has evolved exchange of signals and interruption of one or more of these signals results in failed parasitism leading to possible development of a control strategy. Our general approach has been to assemble suitable germplasm populations for potential sources of resistance, develop simple laboratory assays for screening these germplasm, establish correspondence of our laboratory assay with field performance, establish mode of inheritance of putative resistance traits, and transfer gene sources into elite adapted cultivars using a variety of biotechnological means. Whenever possible, the methods developed will be simple and rapid, in order to facilitate screening large numbers of entries.

We place major emphasis on developing control strategies primarily based on host-plant resistance. To this end, we have in place a very comprehensive *Striga* resistance breeding program in sorghum. Over the last several years, we have generated and selected diverse and outstanding breeding progenies that combine *Striga* resistance with excellent agronomic and grain quality characteristics. All previously known sources of resistance have been inter-crossed with elite broadly adapted improved lines. Almost all resistant sources ever recorded have been assembled and catalogued. We undoubtedly have the largest, most elite and diverse *Striga* resistance germplasm pool, unmatched by any program anywhere in the world. However, while all resistance sources have been introgressed to elite and most readily usable backgrounds, the only mechanism of resistance we have fully exploited has been the low production of germination signal. We have not had the ability to screen for other mechanisms of resistance in the infection chain or the host-parasite interaction cycle. In the last four years, we have placed significant emphasis on developing additional effective methods for screening host plants for *Striga* resistance at stages in the parasitic life cycle beyond germination, including low production of haustorial initiation signal, failure to penetrate, hypersensitive reaction, incompatibility, or general cessation of growth after penetration. Work is currently in progress on refining these assays and integrating them into our plant breeding procedures for effective transfer of genes of *Striga* resistance into new and elite sorghum cultivars.

The wealth of germplasm already developed in this program also needs to be shared by collaborating national programs in *Striga* endemic areas of Africa. To this end, we have organized international nurseries for distribution of our germplasm on a wider scale. This has served as an effective way to network our *Striga* research with NARS that have not been actively collaborating with INTSORMIL. As we combine and confirm multiple mechanisms of resistance in selected genotypes, the efficiency and durability of these resistance mechanisms can be better understood through such a wide testing scheme.

Furthermore, in cooperation with weed scientists and agronomists in various NARS, we plan to develop and test economically feasible and practicable integrated *Striga* control packages for testing on farmers' fields in selected countries in Africa. While most INTSORMIL projects have been directed as bilateral collaborative ventures focusing on individual NARS, this *Striga* project is handled as a regional or more "global" program, because of the commonality of the *Striga* problem and because no other agency has the mandate or is better suited to do the job.

Research Findings

Hypersensitive Response as a Mechanism of Striga Resistance in Sorghum

Appearance of the parasitic weed *Striga* (*Striga* spp.) on host plants in the field is the eventual expression of a series of interactive events between the parasite and its hosts. Empirical breeding for *Striga* resistance in field crops has relied on selection of host plants that allow emergence of few parasitic plants and show little or no loss in productivity of the crop. Plant breeders in several programs around the world have identified sorghum [*Sorghum bicolor* (L) Moench] varieties with good levels of *Striga* resistance using this approach. However, the specific mechanisms of many of these resistance sources have not been properly characterized because of lack of appropriate laboratory procedures that reveal the specific interactions in the early stages of infection. In this study, we report on the identification of sorghum variants with hypersensitive response (HR) to parasitic infection characterized by expression of necrotic lesions at attachment sites discouraging further penetration of the parasite into host roots. We examined the HR reaction of known *Striga* resistant and susceptible sorghum cultivars using an *in vitro* assay developed in our laboratory. All susceptible sorghum cultivars showed no necrosis. In contrast, resistant cultivars, Framida, Dobbs, and a wild sorghum accession, P47121, showed necrosis in over 70% of attached *Striga.* In each of these lines, attached *Striga* were discouraged from penetration and further development. The HR reaction of these genotypes appears to be graded and varied in intensity. The reaction in P47121 was almost twice the intensity of the reaction of Framida. Over 83% of the *Striga* attached on P47121 exhibited discouraged penetration compared to 49% for Framida. These results suggest that P47121 would be a good candidate as a donor parent for an introgression of HR gene(s) for resistance into adapted sorghum cultivars.

Significant progress has been made in breeding for *Striga* resistance in several crops. However, there has been limited understanding of the basic mechanisms associated with resistance to *Striga*. Several hypotheses on possible host resistance mechanisms have been proposed. Most are based on cytological studies and observation of production of exudates *in vitro*. Nevertheless, there appears to be a general parallel between host-pathogen interactions in plant diseases and defense responses triggered during *Striga* invasion. The major limitation to making precise determination of these observations during the development of the parasite appears to be the lack of appropriate bioassays that reveal early interactions between the host and parasite.

One host-resistance mechanism, the hypersensitive response (HR), has been extensively studied in several plant pathogens. The HR generally refers to the appearance of a necrotic region around the site of attempted infection, followed closely by death of the affected host cells within hours of the attack. The HR can be phenotypically diverse ranging from a single cell response to large and spreading necrotic areas in a tissue accompanying parasitic colonization. Necrosis of the affected tissue has been shown, in some situations, to be directly related to the accumulation, oxidation, and polymerization of phenolic compounds. The objective of this study was to identify *Striga* resistant sorghum lines that express HR using an *in vitro* system, the extended agar gel assay (EAGA), a modification of a procedure we had described earlier.

A collection of sorghum cultivars, wild accessions, and breeding lines from our sorghum breeding program were sampled for this study. Seven cultivated sorghum lines (SRN-39, Framida, IS9830, 555, Dobbs, IS4225, and Shan Qui Red) with known field reaction to *Striga* infection, five wild sorghum accessions (P47121, P1885, P14539, P14529, and P12-26), and 95 BC_3F_4 progenies, derived from a cross between P47121 and two male sterile based populations (CK60 and KP9) were evaluated for HR to *Striga* invasion. All seeds were from plants grown at the Purdue University Agronomy Research Center, West Lafayette, IN.

Striga (*S. asiatica* (L) Kuntze) seeds were obtained from the USDA/APHIS, Whiteville, Methods Development Center, Whiteville, NC, courtesy of Drs. Robert Eplee and Rebecca Norris. *Striga* seeds were stored and handled under quarantine restrictions in an approved quarantine laboratory on the campus of Purdue University. All experiments involving *Striga* seeds and seedlings were performed in this facility.

The EAGA is a modification of the agar gel assay. In this assay, large (150 mm) Petri dishes with a thick agar layer were used to support growth of seedlings for a longer period than in the agar gel assay. Because seedlings can be grown for longer periods, effects of signal exchanges between host and parasite as well as host defense responses beyond germination could be observed using the EAGA. With the agar gel assay, we were only able to detect *Striga* germination in response to exudates from host roots with no opportunity to observe post attachment parasitic reactions. Three days following inoculation, each dish was observed for germination, parasitic attachment and host root development, then treated with ethylene to remove any difference in host roots for inducing *Striga* seed germination. The HR was observed when a clear necrotic lesion develops around the attachment site. The reaction normally starts a few hours after attachment and the lesion becomes more intense in 24 h. *Striga* seedling discouragement was observed 3 days following the attachment. Whereas *Striga* seedlings attached on susceptible host roots penetrate and develop, those on resistant roots are discouraged and never penetrate or develop beyond attachment.

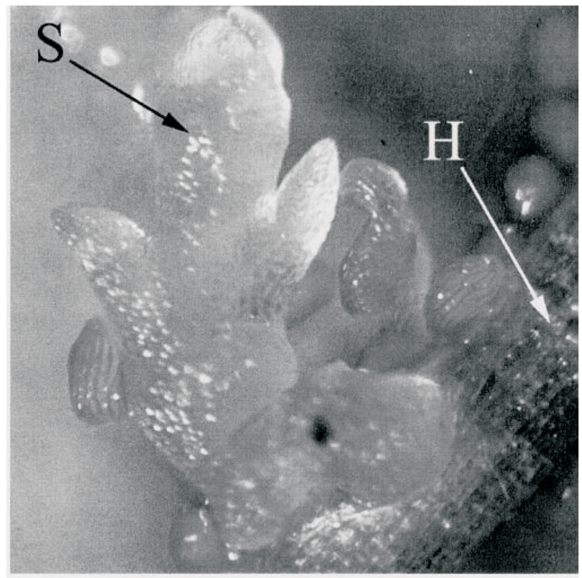
All known susceptible sorghum cultivars had what appeared to be a normal association with *Striga* when observed under the conditions of the EAGA. *Striga* seedlings developed successfully without any apparent sign of stress or damage. However, in some *Striga* resistant sorghum cultivars and wild sorghum accessions, a key host-defense response was observed. In these genotypes, necrotic areas appeared at *Striga* attachment sites on the sorghum root. These necrotic lesions most often start as red spots, which turn brown with time. The lesions were often large and some spread up to 2 mm from the center of attachment, but most remained localized. Attached *Striga* at these necrotic sites often did not develop further (discouraged from penetration), and eventually died on the host.

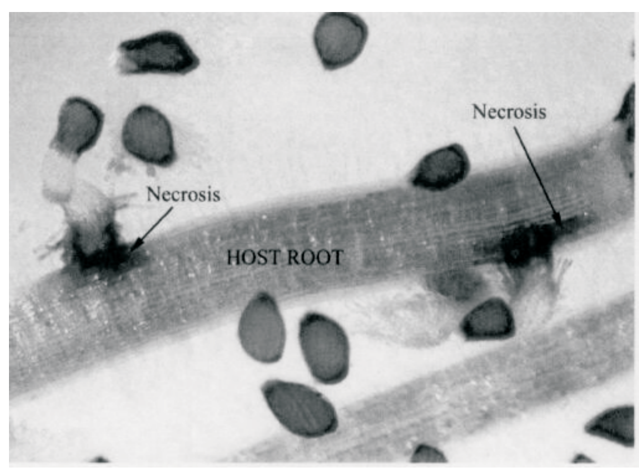
Among sorghum cultivars tested, Framida and Dobbs showed necrosis in about 70% of attached *Striga* and almost 50% of the attached *Striga* were discouraged from penetration. No necrosis was observed on roots of susceptible sorghum cultivars. Some *Striga* resistant sorghum cultivars, including SRN39, IS9830, and 555, also did not show necrotic lesions. These genotypes are resistant to *Striga* because they are low producers of the *Striga* germination signal, as indicated by germination distance. Among the wild sorghum accessions, P47121 (*Sorghum verticilliflorum*) showed necrotic lesions on 89% of the attached *Striga* seedlings. In this genotype, 83% of the total attachment points were discouraged from penetration and further development. Cultivars and accessions screened in this study were clearly and consistently classified into two categories, those exhibiting HR response and those with no necrosis. In both cultivated and wild sorghum accessions, susceptible genotypes induced germination and supported normal growth and development of the parasite.

The EAGA is an effective tool for demonstrating that different *Striga* resistant sorghum cultivars may possess different resistance mechanisms. A widely used sorghum cultivar Framida, with strong field resistance, possesses two mechanisms; it expresses an HR reaction in addition to a low germination stimulant production. Cultivars with moderate field resistance expressed one mechanism, either the low germination stimulant production (555, IS 9830) or a mild HR reaction (Dobbs). Contrary to an earlier report, resistance in sorghum cultivar SRN-39 could not be characterized as involving HR. The HR reaction of genotypes appears to be graded and variable in intensity. A single infected root may show reddening in most but not necessarily all attachment sites. Some attachment sites may appear necrotic early and fade with *Striga* growing normally. Overall, however, lines possessing HR reaction to *Striga* showed greatly reduced percentages of *Striga* attachments and reduced parasitic association relative to susceptible genotypes.

In each of the genotypes that exhibited HR, necrosis was observed at attachment sites as early as three days after infection. Discouragement of parasitic development was evident seven days following infection, reaching a maximum in 12 days after infection. In general, sorghum genotypes that showed necrosis at attachment sites also showed parasitic discouragement. A positive and significant correlation (r = 0.84) was observed between the presence of necrosis and *Striga* seedling discouragement. While parasitic discouragement can be noted, observation made on necrotic tissue is more readily apparent and reliable since this symptom appears early when the health of the host tissue is not of concern.

Hypersensitive response to *Striga* invasion is a readily observable trait with the EAGA reported here as well as with the paper roll assay both of which could be effectively used for germplasm screening. Since HR expression is associated with discouraged attachment of the parasite, it could serve as a powerful *Striga* resistance mechanism.





Deployment of Striga Control Packages

Collaborative international testing of *Striga* resistant sorghum cultivars, developed under the INTSORMIL PRF-213 project, has led to the identification of a number of sorghum varieties to be officially released for commercial cultivation in several countries. In Ethiopia, two *Striga* resistance cultivars were officially released, in 1999, for wide cultivation in *Striga* endemic regions of northwest Ethiopia. In 2002, yet another one of our varieties was identified and recommended for official release in the Amhara region. This cultivar, released under the local name , Brhan (translated as Light) is expected to bring significant relief to the widespread and overwhelming darkness, that is *Striga*, in this region. The *Striga* resistance attributes of Brhan have been found to be superior to our previous releases particularly in the Amhara region.

To promote the extensive use of these varieties and rapid multiplication and distribution of seed in an organized farmer-to-farmer seed multiplication effort, we implemented a pilot project in Ethiopia, as an Integrated *Striga* Management (ISM) package with funds provided by the Office of Foreign Disaster Assistance (OFDA) at the USAID. The package includes seed of *Striga* resistant sorghum, nitrogen fertilizer, and the use of tied ridging as a water conservation measure. The combined use of moisture conservation, improved fertilization, and *Striga* resistant cultivars is expected to provide better control of *Striga* than use of any one of the individual packages. A total of 5.7 tons of seed of the two *Striga* resistant INTSORMIL varieties were produced at Melkassa Research Station. An estimated 1000 farmers in four *Striga* endemic regions of the country have been targeted to receive a package of technologies that includes fertilizer and tied-ridges.

In Tanzania, two of our *Striga* resistant varieties were also recommended for official release and cultivation in the sorghum growing environments of Tanzania where *Striga* has been a significant production constraint. Also in Eritrea, four of our *Striga* resistant cultivars have been identified for verification and wide demonstration in several locations in the country. Furthermore, plans have been made to plant approximately 33 hectares of these four varieties for seed increase in the 2002 crop season to be used in a large scale pilot project in the summer of 2003.

Networking Activities

Workshop and Program Reviews

Participated in the evaluation of a Food Security Project for the Amhara Region in Ethiopia at the invitation of USAID/Ethiopia, May 5-12, 2001, Addis Ababa, Ethiopia.

Participated in a study on survey of available technologies for use in development of drought tolerant crops in Eastern Africa for the Inter-Governmental Agency for Development, May 12-18, 2001, Nairobi, Kenya.

Attended and chaired two sessions at the 7th International Parasitic Weed Conference, 6-8 June, 2001, Nantes, France.

Attended International Conference on Contemporary Development Issues in Ethiopia, 16-18 August 2001.

Organized a stakeholders conference to discuss findings of regional study on state of technologies for drought tolerant crops in East Africa, 27-31 October 2001, Nairobi, Kenya.

Traveled to Ethiopia to initiate a program on community-based improved sorghum seed multiplication and integrated *Striga* management program for Ethiopia and Eritrea, 10-22 December, 2001.

Research Investigator Exchange

Visited University of Paris and the Tropical Ag Res Centre (CIRAD) and held discussions with staff at both institutions regarding collaborative research on sorghum *Striga* resistance, 10-12 June, 2001, France.

Hosted international visitors from Ethiopia, Tanzania, Zimbabwe, and Australia.

Germplasm Exchange

We continue to provide an array of sorghum germplasm from our breeding program to national research programs in developing countries. Our germplasm is provided in either a formally organized nursery that is uniformly distributed to all collaborators that show interest or upon request by a national program of specific germplasm entries or groups from our germplasm pool. Germplasm was distributed to cooperators in 25 countries in 1996, 15 countries in 1997, 10 countries in 1998, and 7 countries in 1999.

Three new *Striga* resistant varieties of sorghum from our program in 2001 were recommend for commercial cultivation in two African countries, one in Tanzania and two in Ethiopia.

Publications

Refereed Papers

Mohammed, A., G. Ejeta, and T. Housley. 2000. *Striga* asiatica seed conditioning and 1-aminoacylopropane-1- carboxylate oxidase activity. Weed Research 41:165-176.

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Ejeta, G. 2001. Exploiting global genetic variation in sorghum improvement. Presented at Kansas State University, Invited seminar, Department of Agronomy. 5 September, Manhattan, Kansas.

Ejeta, G. 2001. The State of Agricultural Research in Sub-Saharan Africa. A keynote address, presented at the International Conference on Contemporary Development Issues in Africa. 16 August, Western Michigan University, Kalamazoo, Michigan.

Ejeta, G. 2001. An African Success Story: the control of a noxious weed. Presented at the Wabash Area Center for Lifetime Learning, 6 November, W. Lafayette, IN.

Sustainable Management of Insect Pests

Project WTU-200
Bonnie B. Pendleton
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Summary

The PI traveled to Botswana, Zambia, and South Africa in April to review sorghum research and establish collaborative projects to manage sugarcane aphid, *Melanaphis sacchari*, sorghum midge, *Stenodiplosis sorghicola*, and other major insect pests and develop integrated pest management (IPM) approaches for insect pests of sorghum in the field and storage. Research was planned with Dr. Munthali, entomologist at the Botswana College of Agriculture, who also will collaborate with current INTSORMIL collaborators from the Department of Agriculture (DAR) in Botswana. Research to develop IPM tactics for managing major insect pests was planned and begun with Drs. Diarisso, Doumbia, and Youm in Mali and with Mr. Abdou Kadi Kadi in Niger. Extract from a Malian plant, *Acacia nigricans*, was used to prevent infestation of stored sorghum grain by lesser grain borer, *Rhyzopertha dominica*. Sorghum lines were evaluated for resistance to sorghum midge and panicle-infesting bugs and will be evaluated again during the 2002 cropping season. Standard plant differentials were used to biotype greenbugs, *Schizaphis graminum*, infesting sorghum and wheat in the Panhandle and South Texas. DNA from sorghum lines developed for resistance to greenbug biotypes E and I was extracted and amplified fragment length polymorphism (AFLP) used to try to locate and map genes for resistance to different biotypes of greenbug. A Malian scientist was identified to come to West Texas A&M University to learn English and begin graduate studies. Graduate education programs of four students were directed and their research begun during 2002. One student assessed effects of temperature on fecundity and longevity of different biotypes of greenbug on sorghum. A student from India evaluated fitness of greenbug biotype I on resistant and susceptible sorghums and wild grass hosts. Another student from India studied effects of different amounts of soil moisture and nitrogen on abundance and longevity of greenbugs on sorghum. A third student from India began research to establish procedures for producing male greenbugs and viable eggs for use in determining genetic differences among biotypes of greenbug. The PI advised extension personnel and the National Grain Sorghum Producers organization on management of insect pests of sorghum and pearl millet. Greenbugs and advice for evaluating newly developed sorghums for resistance to greenbugs were provided to a commercial seed company and to molecular biologists at the Texas Agricultural Experiment Station.

Objectives, Production and Utilization Constraints

Objectives

West Africa

- Establish collaborative research with scientists in Mali and Niger to develop and transfer strategies, especially non-chemical methods, to manage major insect pests and improve yield and income from sorghum and pearl millet.

- Identify a Malian to begin graduate studies in IPM and entomology in the United States.

Southern Africa

- Establish collaborative research to identify and evaluate resistance and develop IPM strategies for insect pests of sorghum in the field and storage.

United States

- Study the biology, ecology, and population dynamics of major insect pests so effective management strategies and longer lasting plant resistance can be developed. Determine the distribution of biotypes of greenbug in Texas. Assess fitness of greenbugs on wild and cultivated hosts to better understand insect-plant interactions. Assess effects of temperature on the biology of different greenbug biotypes to determine the optimum temperature for evaluating resistance to greenbug in sorghum and better understand how biotypes of greenbug develop.

- Assess effects of agronomic practices on abundance of and damage caused by insect pests. Study effects of soil fertility and moisture on abundance of greenbugs on sorghum.

- Collaborate with breeders to evaluate sorghum germplasm for greater yield potential and tolerance to major insect pests.

- In collaboration with molecular biologists, use biotechnology techniques to study insect genetics and locate genes for resistance in improved sorghum lines so the genetic relationship between insects and resistant plants can be understood and durability of sorghum resistance increased.

- Provide technical advice and assistance on major insect pests and IPM tactics and how they function to assist extension personnel, commodity organizations, and the sorghum industry to transfer pest management information to sorghum and pearl millet farmers.

- Supervise graduate student research in entomology and IPM. A student from the United States is studying the effect of temperature on fecundity and longevity of greenbug biotypes on sorghum. A student from India is evaluating fitness of greenbugs on susceptible and resistant sorghum and wild hosts. Another student from India is evaluating the effect of different amounts of soil moisture and nitrogen on abundance of greenbugs on sorghum. A third student from India began testing procedures to produce male greenbugs and fertile eggs so different biotypes can be mated and polymorphism of the progeny studied to identify genetic differences among biotypes.

- Participate in Entomological Society of America and other professional and scientific meetings and activities. The PI was asked to organize sorghum entomology symposia at several up-coming meetings.

Constraints

West Africa

Abiotic stresses and such biotic constraints as insects, diseases, and *Striga* limit production of sorghum and pearl millet in West Africa. The most damaging insect pests are sorghum midge, aphids, panicle-infesting bugs, and stalk borers on sorghum, and millet head miner, *Heliocheilus albipunctella*, on pearl millet. Sorghum midge can destroy 100% of sorghum kernels in the field. Recently, greenbugs destroyed 60% of sorghum in southern Mali. Damage by panicle-infesting bugs and associated infection by pathogens reduce grain yield and quality and render the grain unusable for human consumption. Stalk borers bore into sorghum and kill the central shoot, causing "deadheart", or break the peduncle. Larvae of millet head miner cut flowers and tunnel in kernels of spikes of pearl millet. Other insects could become pests when agronomic practices are changed and new varieties of sorghum or pearl millet are used. Effective management of insect pests requires a multi-disciplinary team with knowledge of entomology, plant pathology, plant breeding, and cereal quality.

Southern Africa

In Southern Africa (mainly Botswana and South Africa), sugarcane aphid; sorghum shoot fly, *Atherigona soccata*; sorghum midge, and stalk borers infest and reduce yield of sorghum in the field. Beetles destroy stored sorghum grain. Few taxonomic keys are available for identification of insect pests in Southern Africa. This project will assist a team to improve production and develop IPM strategies for sorghum insect pests in South Africa.

United States

Major insect pests include greenbug, sorghum midge, and panicle-infesting bugs and caterpillars. Ecosystem disruption caused by monoculture of sorghum increases the severity of insect pests and results in increased production costs and reduced yield. Insecticides prevent damage and yield loss, but overuse results in increased production costs, disruption of the ecosystem, outbreaks of secondary arthropod pests, resurgence of the targeted pest, and environmental contamination. Biology, insect-plant interactions, amounts of damage, and economic and ecological costs associated with the use of chemicals to control insect pests need to be understood better. Biological and cultural management tactics such as use of resistant cultivars are needed to prevent damage by insect pests. Development of resistant sorghums requires collaboration among plant breeders, entomologists, and molecular biologists.

Research Approach and Project Output

This project emphasizes collaborative research and education. The IPM approach is used to develop strategies to manage insect pests economically, ecologically, and environmentally. For effective IPM, the insect pest must be identified correctly; its biology, ecology, and population dynamics understood; abundance determined in relation to crop damage and yield loss; economic threshold determined; and direct control tactics used, especially conservation of natural enemies, agronomic practices, resistant varieties, and chemicals only when necessary. Information and technology from the research is being transferred to extension personnel, farmers, and others.

West Africa

Collaborative research to manage insect pests of sorghum and pearl millet was planned with Drs. Diarisso, Youm, and Doumbia from Mali and Mr. Abdou Kadi Kadi from Niger. Sorghum has been planted to assess the effect of different crop residue practices on the abundance of sorghum midges and stalk borers that survive after diapause in Mali. Sorghum crop residue practices in Mali will be inventoried and evaluated for effectiveness against sorghum midge and stalk borers. In collaboration with Mr. Abdou Kadi Kadi, a survey will be conducted in sorghum production areas of Niger to assess damage caused by sorghum midge. In collaboration with Mr. Abdou Kadi Kadi, abundance and causes of mortality of different life stages of naturally occurring millet head miner will be assessed and sampling methodology verified so natural enemy-host interactions can be understood for pearl millet in Niger.

In collaboration with Dr. Peterson, Dr. Diarisso, and Mr. Abdou Kadi Kadi, sorghum lines and landraces will continue to be evaluated for resistance to insect pests in Mali and Niger. Percentage of infestation by sorghum midge, panicle-infesting bugs, and aphids; damage rating score; and yield were assessed of 67 sorghums from the Mali breeding program, INTSORMIL plant breeders, and ICRISAT during the 2001 growing season at Sananko, Cinzana, and Kita, Mali (refer to the West Africa country reports). In Niger, Mr. Abdou Kadi Kadi found sorghum genotypes 99SSDF9-18, 99SSDF9-21, 99SSDF9-29, 99SSDF9-33, 99SSDF9-35, DJ6514, F10SSDF9-35, ICSV197, ICSV745, ICSV90001-02, ICSV90011, ICSV90013, and ICSV93077 resistant to sorghum midge. ICSV90001, ICSV90002, ICSV90011, and ICSV90013 were highly resistant, with grain losses of 16.7, 18.2, 6.4, and 2.1%, respectively. The experiments will be repeated during 2002.

Tiecoura Traore from Mali was identified to come to West Texas A&M University to learn English and begin graduate studies in IPM and entomology.

In collaborative research, Dr. Diarisso used five grams of powder from local *Acacia nigricans* plants to treat 10 grams of kernels of each of six sorghums (Bibalawili – resistant to lesser grain borer, ICSH89002 – susceptible, BOPR11, BTx378, LG2CG3S, and LG21CG3C) in three replications. Kernels were infested with 30 lesser grain borer adults on 14 February 2002. The insects were removed two weeks later. Adults that emerged were counted each week. During peak emergence five weeks after the insects were removed, most lesser grain borers (48) emerged from nontreated kernels of ICSH89002. Fewer insects emerged from treated than from nontreated kernels, except for LG21CG3C from which the same number of insects emerged in both treatments (Table 1). Lesser grain borers attacked more kernels of nontreated LG2CG3S (36.4%), but fewest kernels when that sorghum genotype was treated with *Acacia* (11.8%). Least weight was lost from kernels of treated BOPR11 (4.0%), while most weight was lost from nontreated kernels of ICSH89002 (22.9%).

Southern Africa

From 31 March through 14 April, sorghum research was reviewed and collaborative research projects planned with scientists in Southern Africa. Sorghum was evaluated for resistance to sugarcane aphid and sorghum midge in Botswana and South Africa. Research was planned with Dr. Munthali to assess natural enemies and population dynamics of major insect pests of sorghum in Botswana. Collaboration in entomology was proposed among Dr. Munthali at the Botswana College of Agriculture, scientists at the Department of Agriculture (DAR), and INTSORMIL. Sorghum lines will be evaluated for resistance to sugarcane aphid, sorghum midge, sorghum shoot fly, stalk borers, and stored grain insect pests. In South Africa, sorghum genotypes were identified with excellent resistance to sugarcane aphid in the greenhouse (seedling stage) and field (adult stage).

United States

Greenbugs infesting sorghum, small grains, and wild hosts were collected in the Panhandle and South Texas, and standard plant differentials were used to identify the greenbugs to biotype. All greenbugs collected in fields in Texas were identified as biotype I. In collaboration with Drs. Burd and Shufran, additional samples of greenbugs will be collected and biotypes determined.

Table 1. Lesser grain borers that emerged per week, percentages of kernels attacked, and proportion of weight of damaged versus nondamaged kernels when sorghum was treated with powder of *Acacia nigricans* at Sotuba, Mali.

Sorghum	Treatment	Adults emerged per week	Percentage of kernels attacked	Weight of damaged vs. noninfested kernels (%)
Bibalawili	*Acacia*	9.9	23.5	12.1
Bibalawili	Check	6.1	13.8	6.1
ICSH89002	*Acacia*	6.6	15.3	7.9
ICSH89002	Check	17.1	29.7	22.9
toBOPR11	*Acacia*	9.1	12.6	4.0
BOPR11	Check	13.8	13.8	8.9
BTx378	*Acacia*	8.5	15.6	9.2
BTx378	Check	9.7	24.8	15.2
LG21CG3C	*Acacia*	7.8	17.5	11.4
LG21CG3C	Check	7.8	20.8	9.1
LG2CG3S	*Acacia*	8.9	11.8	6.5
LG2CG3S	Check	14.5	36.4	22.2

In collaboration with Dr. Zhu-Salzman, AFLP polymorphic markers that differentiate sorghum greenbug biotypes were developed for use in identifying unknown greenbugs from the field. The PI evaluated resistance of 300 sorghum lines Dr. Peterson developed for resistance to greenbug biotypes E and I, and Dr. Zhu-Salzman extracted DNA from the sorghum and is using AFLP to try to locate and map genes for resistance to different biotypes of greenbug.

Master's student, Kishan Sambaraju, evaluated fitness of greenbug biotype I on resistant and susceptible sorghums and wild grass hosts. Greenbugs are thought to survive on wild grasses when grass crops are not available. Seeds of susceptible RTx430 sorghum; resistant LG-35 sorghum; Johnsongrass, *Sorghum halepense*; Arriba western wheatgrass, *Agropyron smithii*; and jointed goatgrass, *Aegilops cylindricum*, were sown in a greenhouse. A biotype I greenbug was placed in a 2.5-cm^3 plastic cage clipped onto a plant leaf. The original greenbug was removed after it produced a nymph. The nymph was retained until it produced offspring, which were counted and removed each day. The number of days the greenbug lived was recorded. The number of nymphs produced per day differed significantly among the grass hosts (Wilk's Lambda = 0.045, $F_{(32,52)}$ = 34.7, P < 0. 0001). Significantly fewer nymphs were produced on western wheatgrass than on the other grasses (Table 2). Only 35% as many nymphs (22.8) was produced per greenbug on western wheatgrass as on susceptible sorghum (64.4 nymphs). Average longevities of greenbugs were significantly less on western wheatgrass and jointed goatgrass (19.2 days) than on grasses of the genus *Sorghum.* The experiment will be replicated two more times using several additional species of wild grasses.

Master's student, Anastasia Palousek, assessed effects of 14-27 and 22-35° C temperatures (daily low-high cycle) on the biology of greenbug biotypes E and I on sorghum to determine the optimum temperature for evaluating resistance and try to understand how greenbug biotypes develop.

Table 2. Number of nymphs produced and longevity per biotype I greenbug on grass hosts.

Host	Total number of nymphs	Longevity (days)
RTx430 sorghum	64.4 a	26.9 a
Johnsongrass	60.1 a	27.6 a
LG-35 sorghum	57.4 a	28.2 a
Jointed goatgrass	61.0 a	19.2 b
Western wheatgrass	22.8 b	19.2 b

Means followed by the same letter within a column are not significantly different at p = 0.05 (Fisher's LSD)

Twenty plants of RTx430 sorghum were used for each combination of temperature and greenbug biotype. A single greenbug enclosed in a 2.5-cm^3 clear plastic cage was attached to each of two leaves on a sorghum plant that had seven true leaves. The infested sorghum kept in an environmental chamber. The original greenbug was discarded after it produced a nymph which was retained. When the greenbug in each cage began producing offspring, the nymphs produced per day were counted and removed. The greenbug was monitored until death. Each biotype E greenbug produced significantly more nymphs per day (1.5) and overall (33.8), especially at warmer temperatures, than did biotype I greenbugs (1.2 nymphs per day and 27.8 overall) (Table 3). Significantly fewer greenbugs were produced per day at 14-27 than at 22-35° C. Greenbugs lived four times longer and produced 3.4 times more nymphs at the cooler than the warmer temperature, but longevity did not differ between the two biotypes (approximately 23 days). The experiment will be repeated using 10-23 and 18-31° C temperatures.

Master's student, Suresh Veerabomma, studied effects of amounts of soil moisture (-1/3, -1/2, and –3 bars) and nitrogen (50, 100, and 150 ppm) on abundance and longevity of greenbug biotype I. A greenbug enclosed in a clip cage was attached to a leaf of each of 90 sorghum plants, 10 per treatment combination, in a greenhouse. Numbers of

Table 3. Effect of temperature on greenbug biotypes E and I.

Temperature (°C)	Nymphs produced per day	Fecundity	Longevity (days)
14-27	1.3 a	47.6 a	37.5 a
22-35	1.5 b	14.0 b	9.4 b

Means followed by the same letter within a column are not significantly different at $p = 0.05$.

greenbug nymphs produced per day and total longevity were assessed. Soil moisture, but not nitrogen, significantly affected greenbug fecundity, with almost twice as many nymphs produced per greenbug on sorghum in soil with –1/3 bar (44.2 nymphs) as with –3 bars of moisture (24.3 nymphs) (Table 4). Greenbug longevity was affected significantly by different amounts of soil moisture and nitrogen. Fecundity and longevity were most per greenbug on sorghum planted in soil with –1/3 bar of moisture and 100 ppm of nitrogen.

Table 4. Effect of soil moisture and nitrogen on biotype I greenbugs on sorghum.

	Total number of nymphs produced per greenbug	Number of days each greenbug lived
Moisture (bars):		
-1/3	44.2 a	23.9 a
-1/2	42.0 a	23.4 a
-3	24.3 b	19.0 b
Nitrogen (ppm):		
50	34.8 a	21.6 ab
100	39.3 a	23.5 a
150	36.5 a	21.2 b

Means followed by the same letter for a treatment within a column are not significantly different at $p = 0.05$ (Fisher's LSD).

Networking Activities

Workshops

The PI participated in the Workshop on Sustainable Agroecosystems in Semiarid Regions (14-27 June 2002, Canyon, Texas) and the 50th Annual Meeting of the Southwestern Branch of the Entomological Society of America (24-27 February 2002, Guanajuato, Mexico) and gave invited presentations at the Entomology Science Conference (30-31 October 2001, College Station, Texas) and 49th Annual Agricultural Chemicals Conference (19 September 2001, Lubbock, Texas).

Research Investigator Exchanges

Botswana, South Africa, and Zambia – 31 March–14 April 2002. In Botswana, the PIs of TAM-222, TAM-223, and this project met with four INTSORMIL collaborators in the Department of Agricultural Research and with faculty and administrators of the Botswana College of Agriculture to discuss INTSORMIL and establish collaborative research. Entomology studies at Sebele Research Station were viewed. In Zambia, sorghum breeding and evaluation nurseries were viewed, and we met with the Director of U.S.-A.I.D./Zambia, Chief Agriculture Research Officer of the Ministry of Food, Agriculture, Director of the Golden Valley Agricultural Research Trust, and Permanent Secretary to the Minister of Agriculture to discuss potential contributions of INTSORMIL collaboration and the importance of sorghum to the food security of Zambia. In South Africa, we met with the entomologist and plant pathologist from the Agricultural Research Corporation-Grain Crops Research Institute and personnel and students of cereal quality at the University of Pretoria to discuss present and future INTSORMIL collaboration in sorghum and pearl millet research and technology transfer. Sorghum was evaluated for resistance to sugarcane aphid and sorghum midge.

Research Information Exchange

The PI assisted extension entomology specialists with management of insect pests of sorghum and pearl millet and advised the National Grain Sorghum Producers organization on IPM of sorghum insect pests. Information was provided to the Intensive Sorghum Committee of the U.S. Grains Council for sending food sorghums to Southern Africa.

Mr. Barry Miller with Pioneer Hi-Bred International, Inc. at Plainview, Texas, was assisted with evaluating newly developed sorghums for resistance to greenbugs. Greenbugs and information on how to evaluate resistance were provided to Dr. Yiqun Weng, a Texas Agricultural Experiment Station molecular biologist who is using biotechnology techniques to locate wheat genes resistant to greenbugs.

Supplies were provided for Dr. Diarisso to conduct research in Mali. Insect-rearing cages, preservation supplies, and identification books were purchased for Dr. Munthali in Botswana.

Publications and Presentations

Publications

Brown, E.D., J. Trybom, W.A. Colette, R.C. Thomason and B.B. Pendleton. 2002. Effects of systemic seed treatment insecticides imidacloprid and thiamethoxam on sorghum hybrids. International Sorghum and Millets Newsletter (in press).

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Peterson, G.C. and B.B. Pendleton. 2001. PROFIT – Productive Rotations On Farms In Texas: a new paradigm for sorghum research and information delivery in Texas. Pp. 82-92. In Proceedings of the 56th Annual Corn and Sorghum Research Conference. Chicago, IL. December 5-7, 2001. American Seed Trade Association, Inc., Alexandria, VA.

Presentations

Gary C. Peterson and Bonnie B. Pendleton. 2001. PROFIT - Productive Rotations On Farms In Texas: a new paradigm for sorghum research and information delivery in Texas. 56th Annual American Seed Trade Association Corn and Sorghum Research Conference, 5-7 December 2001, Chicago, IL.

Bonnie B. Pendleton. Greenbug biotypes. Entomology Science Conference, 30-31 October 2001, College Station, TX.

Bonnie B. Pendleton. Update on "PROFIT." Entomology Science Conference, 30-31 October 2001, College Station, TX.

Edward D. Brown and Bonnie B. Pendleton. Effects of systemic seed treatment insecticides Cruiser and Gaucho on sorghum hybrids. Entomology Science Conference, 30-31 October 2001, College Station, TX.

Bonnie B. Pendleton. What's new for sorghum pest management? 49th Annual Agricultural Chemicals Conference, 19 September 2001, Lubbock, TX.

Edward D. Brown, Bonnie B. Pendleton, W. Arden Colette, Ronald C. Thomason and James Trybom. Effect of systemic seed treatment insecticides imidacloprid and thiamethoxam on sorghum hybrids. 49th Annual Agricultural Chemicals Conference, 19 September 2001, Lubbock, TX.

Sustainable Production Systems

Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL-Priority Countries

Project PRF-205
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Summary

The focus of this past year's research has been on the diffusion of new technologies. Information was a critical variable for successful introduction of the new sorghum cultivar and inorganic fertilizer in Tigray, Ethiopia and also for inorganic fertilizers in Niger. From this and other research, we are convinced that the main determinant of technology introduction is for farmers to see it in the field in conditions similar to their own. Governments can accelerate the diffusion by creating an environment in which it is more profitable to use the technology and by improving the functioning of input markets.

There were highly significant complementary effects from the combination of manure and inorganic fertilizer. This is further evidence that these two inputs are complements rather than substitutes.

There was a preference for using the *Striga*-resistant cultivars on the lighter soils, thereby taking advantage of their earliness. Conversely, the inorganic fertilizer was concentrated on the vertisols. In the last two years, various water-retention techniques have been introduced on a large scale in this region of Tigray to reduce the runoff on the crusting soils.

A continuing problem in Niger is the governmental emphasis on maintaining a low price of millet for the benefit of urban consumers. This reduced profitability decreases the incentives to intensify production. Nevertheless, an increasing diffusion of various types of fertilization was being undertaken even in this low rainfall, high-risk agriculture. This indicates again the importance of the demonstration and information variables discussed above.

In Mali, modeling for the agricultural sector compared alternative research-developmental strategies. Investments in sorghum for the semiarid zone gave higher returns to society than either sorghum for the higher-rainfall zone or maize for the same zone. This resulted from the larger yield gap (difference between experiment-station and average-farmer yields) and the larger number of sorghum producers in the dryland zone. Investment in dryland agriculture can not only reduce poverty but also is a high-return activity.

Objectives, Production, and Utilization Constraints

The general objectives of this research are:

- Estimate the potential effects of new technologies
- Identify constraints to their introduction
- Recommend complementary policies to accelerate the introduction process.

In this period there were three primary areas of research: (1) a diffusion study in Tigray to estimate the effects of the adoption of *Striga*-resistant sorghums and associated technologies), (2) an analysis of the introduction of inorganic fertilizer into a semiarid region of Niger in which there have been long-term inorganic fertilizer experiments, and (3) a comparison of the returns to the society of three alternative research-development strategies in southern Mali involving sorghum and maize.

Research Approach and Project Output

Striga-Resistant Sorghums and Associated Technologies in Tigray, Ethiopia

In last year's annual report, we described the results of a survey of 90 farmers of new technology introduction into the dryland regions in the far north of Ethiopia. After seeing the *Striga*-resistant cultivars in regional trials, farmers had pushed the government to release them as new cultivars. Three new *Striga*-resistant cultivars were released in 1999 and 2000. The diffusion is still in the early stages, but we were interested in the factors associated with the initial rapid diffusion and in the complementarity of the various new technologies.

In the statistical analysis, we analyzed the diffusion process for both the adoption of the *Striga*-resistant cultivars and of inorganic fertilizer (Tables 1 and 2). For both technologies, the most important factors were farmers' information and knowledge about technology performance, profitability, and liquidity. For the *Striga*-resistant cultivar, there were several ways of measuring farm-level information; two of them were highly significant. Participation in the local administration of farmers' groups (EXEC) helped inform and give farmers access to the new cultivars. The cultivars were still very new in the community. Forty-nine percent of the non-adopting farmers had not even heard about them. A variable for farmers' perceptions of the new technologies with respect to their technical characteristics (TECHPRCP) was also highly significant.

A variable for the farmers' perception of the riskiness of agriculture (RISKPRCP) with respect to rainfall was also highly significant. Besides *Striga* resistance, the new sorghum cultivars are earlier than traditional cultivars. Hence, they have a higher probability for drought escape. This was undoubtedly one of the factors farmers appreciated in the first year of trials, 1998, when there was a drought. The downside of earliness is that there is less potential to respond to inputs because the plant is in the field less time.

There was a significantly higher diffusion of the new cultivars on the lighter soils. On these soils the water-availability problem generally results from the rapid percolation of water through the soil beyond the reach of the plant.[1] The significance of this variable (SOIL) and of the variable indicating greater perception of rainfall risk indicated an appreciation of the drought-escape potential of the new cultivar.

Also interesting were the variables that were not significant. We expected a positive interaction between the new cultivars with both the water-retention technologies (WRT) and inorganic fertilizers (FERT), but there were no significant effects. Water-retention technologies were being pervasively introduced (see the annual report of last year); the earliness of the new cultivars resulted in less potential for a fertilizer response. Nor did the number of livestock units

Table 1. Determinants of the diffusion of the *Striga*-Resistant sorghum cultivars in Tigray, Ethiopia (Tobit).

Variable	Normalized coefficient	T-ratio
EXEC	0.91937	2.6176**
FRMSZ	0.11155	1.3786
TLU	-0.37326E-01	-0.88678
FERT	0.80013	1.1223
WRT	0.30112	0.61822
SOIL	0.80792	2.1597**
TECHPRCP	3.9719	5.7727***
RISKPRCP	0.25748	2.0379**
Log-likelihood function	-15.309278	
Log-likelihood ratio	3.697	

Mean square error = 0.19853257E-01
Mean error = 0.26605625E-02
Squared correlation between observed and expected values = 0.41176
*** significant at 1%
** significant at 5%

Source: Wubeneh, Nega. 2002. "Farm Level Adoption of Resistant Sorghum Varieties and Inorganic Fertilizers in the Tahtay Adiabo Woreda of Tigray Region, Ethiopia,"unpublished Master's thesis. West Lafayette, IN: Purdue University, Dept. of Agricultural Economics.

Variable definitions:
EXEC - binary variable: 1 if the farmer is an official of the local administration; 0 otherwise.
FRMSZ - farm size measured in hectares.
TLU - tropical livestock unit.
FERT - quantity of fertilizer used on sorghum measured in kg ha^{-1}.
WRT - water-retention techniques measured as a binary variable:1 if the farmer is using water-retention techniques and 0 otherwise.
SOIL - soil type measured as a binary variable: 1 if the soil texture is light and medium (Luvisols, Leptisols, and Cambisols); 0 if heavy texture (Vertisols).
TECHPRCP - Index measuring the farmer's perception of the characteristics of the new cultivars.
RISKPRCP - Farmer's perception of rainfall risk measured by the farmer's subjective estimates of the probability of poor years.

Table 2. Determinants of the diffusion of inorganic fertilizer in Tigray, Ethiopia (Tobit model).

Variable	Normalized coefficient	T-ratio
FMLYG13	0.20265	2.0068**
FRMSZ	-0.22693	-2.9477***
EXTEN	0.83570E-01	2.5707**
WRT	0.13945	0.4224
MANURE	0.25902E-01	2.5206**
SOIL	-0.52770	-2.0011**
RISKPRCP	-0.63765E-01	-0.6372
Log-likelihood function	-2.0941595	
Log-likelihood ratio	0.535484	

Mean square error =0.77807751E-02
Mean error = -0.41727183E-02
Squared correlation between observed and expected values = 0.24336
** significant at 1%
** significant at 5%
* significant at 10%

Source: Wubeneh, Nega. 2002. "Farm Level Adoption of Resistant Sorghum Varieties and Inorganic Fertilizers in the Tahtay Adiabo Woreda of Tigray Region, Ethiopia," unpublished Master's thesis. West Lafayette, IN: PurdueUniversity, Dept. of Agricultural Economics.

Variable definitions:
FMLYG13 - number of adults aged 13 years and older in the household.
FRMSZ - farm size measured in hectares.
EXTEN - number of times the farmer has been visited by Extension agents during the season.
WRT - water-retention techniques measured as a binary variable: 1 if the farmer is using water-retention techniques and 0 otherwise.
MANURE - quantity of manure used in quintals.
SOIL - soil type measured as a binary variable: 1 if the soil texture is light and medium (Luvisols, Leptisols, and Cambisols); 0 if heavy texture (Vertisols).
RISKPRCP - Farmer's perception of rainfall risk measured by his subjective estimates of the probability of poor rainfall years.

[1] On the heavier vertisols, also frequently found in the region, the problem of water availability is usually associated with runoff though water logging can also be a problem especially on vertisols.

have a significant effect as expected. The farm-size variable was almost significant.

Shifting to the diffusion of inorganic fertilizer, information was again highly significant. In this case it came from extension visits (EXTEN). Being in the leadership of the farmers' groups[2] did not matter here since this technology has been out a sufficiently long time for the extension service to be knowledgeable and promoting it. Nor was the risk perception variable significant. Both diffusion equations indicate the importance of information for accelerating the introduction of the two new technologies, though in the two cases information came from different sources.

Family size was positively significant, indicating the importance of family labor in the adoption of inorganic fertilizer. This technology increases the demand for labor. Farm size had a significant negative sign. Smaller farms produce more intensively and use more inputs. Manure use was highly complementary to inorganic fertilizer, as expected. The soil variable had the opposite sign from the case of the new cultivars. Farmers preferred to fertilize on the heavier vertisols as these soils have higher initial soil fertility and water-holding capacity than the sandy soils. The further addition of more nutrients has a higher chance to be successful in increasing yields. Again, the water-retention variable had no effect; that was a surprise, but the dummy variable for soils was picking up the soils with higher water holding capacity.

Fertilization of Millet in Niger. In the Sahel there is much debate on the profitability and riskiness of fertilizers. One hypothesis to explain the observed lag in diffusion of fertilization is that farmers need to see concrete results from fertilization before they will adopt. In the farm-level observations in the semiarid zone of Niger, 100 millet producers were interviewed in five villages. In two of these villages there had been long-term soil-fertility experiments so farmers there were knowledgeable about the potential responses and variability of response to inorganic fertilizers.

With liberalization (removal of state intervention and elimination of fertilizer subsidies) and the continuing efforts of government to prevent the millet price from increasing when there are disruptions to supply, the real price of millet (relative to the price of inorganic fertilizer) declined substantially in the '90s (Abdoulaye, 2002). Nevertheless, in certain regions of semiarid Niger, farmers continue to utilize small quantities of inorganic fertilizer on millet. What are the factors associated with this diffusion of fertilizer?

Exposure to the on-farm trials has a highly significant effect on the adoption of fertilization (Table 3). The price of fertilizer relative to the price of millet also had a significant positive effect. Families with migrating family members have the cash that they bring back as a source of liquidity for buying fertilizer. Higher wealth means not only more liquidity but also the increased ability to take risks. Manure use had the expected sign, indicating complementarity with inorganic fertilizer but it was not significant. Nor were the Other Activities (another liquidity variable) or Area variables.

Table 3. Determinants of the diffusion of inorganic fertilizer in Niger (Tobit model).

Independent variables	
Relative price of fertilizer Migration	-21.64(-2.02)**
Wealth	12.64(1.91)*
On-farm trials	2.56 (2.27)**
Manure use	37.75(2.26)**
Other activities	19.35 (0.81)
Area	25.44(1.51)
Constant	-4.67(-0.77)
	2.44 (0.47)
Number of observations	99
Overall significance level	0.28

Log-likelihood function = -363.74. Likelihood ratio test: ^{2} = 27.22* with 7 degrees of freedom. The numbers in parentheses are values of T-statistic for each coefficient. (*) indicates significance at 10% level and (**) indicates significance level of 5%. Overall significance level is the the squared correlation between observed and expected values.

Source: Abdoulaye, Tahirou, and John H. Sanders. 2002. "Economics of Fertilizer Use in Semiarid African Agriculture: Niger Experience." Mimeo. West Lafayette, IN: Purdue University, Dept. of Agricultural Economics.

Introducing New Sorghum Technologies in Mali. During the last two decades of support to agricultural development in developing countries, there has been a concentration on irrigated and higher-rainfall regions. As malnutrition and poverty have been returning to the development agenda there is a focus shift to the drylands primarily for income distribution reasons as these are the regions where there is a concentration of the rural poor.

However, there are also efficiency reasons for shifting attention to the drylands. Where water availability and soil fertility can be improved, the drylands have a comparative advantage over the higher-rainfall regions due to the combination of more hours of sunlight and less disease pressure. The highest crop yields in the world are obtained in the former drylands, such as in Israel, Australia, and California. Often the new system includes irrigation, but there are a series of technologies to better use the available water as alternatives where irrigation is not technically or economically feasible. On the heavier soils where crusting is the major problem, these are water-retention technologies. On the sandier soil, it is often critical to slow infiltration so that it is accessible to the plant.

With the previous concentration on crops in the higher rainfall or irrigated regions, much of the yield gap between farmer and experiment stations often has been closed. Hence, there are cases as in Mali where there is a larger yield gap presently in the dryland regions. In Figure 1, note the yield-gap comparison between sorghum and maize.

Using a sector model, Vitale (2002) investigated the hypothesis of higher social returns from concentrating on the dryland crop. Vitale evaluated the returns to society from

[2] For the new cultivar, extension visits were not a significant variable either with or without the variable for membership in the leadership of the farmers' organization.

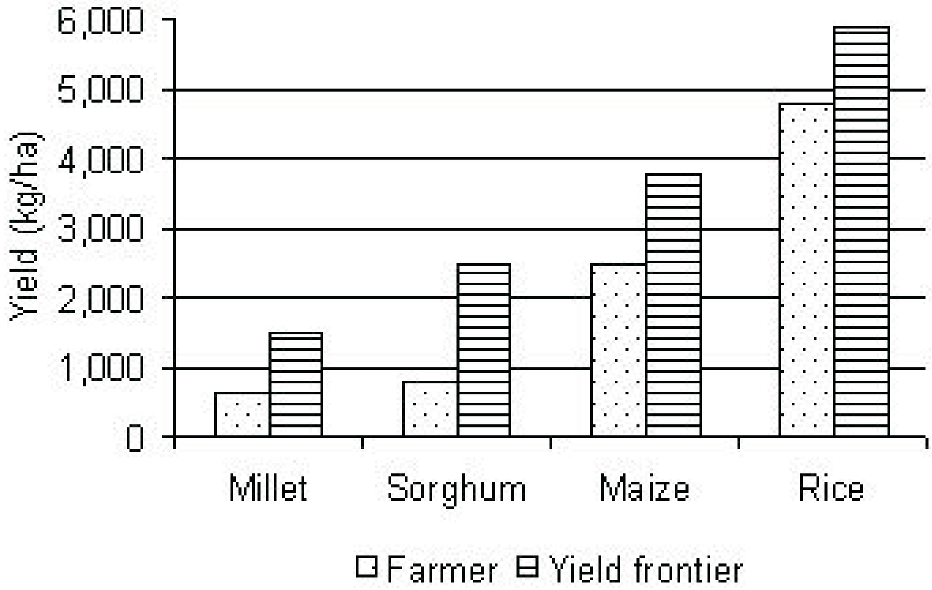

Figure 1. Experiment station and farmer yields for the cereals in Mali
Source: Vitale and Sanders, 2002, p. 24.

programs to introduce three new technologies – new technology in sorghum first for the higher-rainfall region and then the lower one, and new technology in maize for the higher-rainfall zone. For the semiarid zone, ridging for water retention has already been extensively introduced into southern Mali. It was only necessary then to introduce moderate inorganic fertilizer levels and the new sorghum cultivar.[3] For the higher-rainfall regions, the new technology also involved more fertilizer (as farmers were already using moderate fertilizer levels) and new cultivars. The new technology for sorghum in the dryland areas gave a smaller yield increase than either technology for the higher-rainfall zone. However, there were substantially more farmers in the dryland region producing sorghum. Even with conservative assumptions about the percentage of farmers adopting the new technology, the returns to society were considerably higher with a concentration on the sorghum technology for the semiarid zone than on either technology for the higher-rainfall zone (Vitale and Sanders, 2002). So for both efficiency and equity (income distribution) reasons, there are now good reasons for national agricultural research organizations and donors to put more attention on the lower rainfall regions.

Networking Activities

Workshops

After submitting a two-volume report on the contract for IFAD to identify new technologies for the drylands of the Horn, a workshop was held by IFAD with financial support from USAID/REDSO and technical coordination of INTSORMIL. The workshop took place in Nairobi in November 2001. The contributors to the fieldwork gave reports on their particular contributions. Sanders gave an overall summary of the report with an emphasis on future projects; all the team members responded to questions from the agricultural professionals representing the six countries involved. Then discussion sections were held and reports made back to the plenary group for recommendations on project proposals to respond to the constraints identified for introducing new technologies for the drylands of the Horn at a more rapid rate. After this workshop, Sanders and the other team participants, including Kidane Georgis from EARO and Peter Esele from NARO,[4] wrote five research proposals for IGAD on various aspects covered in their two-volume diagnostic of the drylands in the Horn.

Sanders attended an Experts Consultation on Agricultural Development in the Sahel in Bamako, Mali from April 23-26. This meeting was called by ICRISAT at the request of the Common Fund for Commodities, to which ICRISAT had submitted a research proposal. Sanders made two presentations, one on the analysis of factors determining the productivity of millet and sorghum in West and Central Africa and the other on the INTSORMIL collaborative program in the region. Then Sanders spent a week working with Barry Shapiro on a joint project between ICRISAT and INTSORMIL on marketing new millet cultivars in four Sahelian countries. This project evolves out of the millet re-

[3]Some demand expansion and increase in liquidity available were also required but the former is already being observed and the latter will naturally occur as the technology process enables higher incomes and these higher incomes allow increased liquidity for input purchase the next season.

[4]EARO and NARO are the national agricultural research agencies in Ethiopia and Uganda, respectively.

gional network led by Ouendeba Botorou . Presently, a new class of entrepreneurs is developing in several Sahelian countries that make processed products, such as couscous of millet, from the higher-quality white sorghums. Demand is rapidly increasing in urban areas of the Sahel and there have been exports to Europe targeting the migrant community. Several of the women entrepreneurs complained that they have not been able to buy sorghum at a sufficiently rapid rate to respond to the rapidly increasing demand. So the project is seeking to improve the ties between entrepreneurs and farmer cooperatives. The farmers will produce the higher-quality white sorghums; there are advance contracts. Because of little or no experience with advance contracts, there is a high probability of contract default by one side or the other. Various NGOs are involved in the four countries and are trying to reduce this risk to the gradual evolution of better-functioning markets. Our economics program considers this both as a developmental activity and a research project to estimate the income gains from various types of marketing innovation and the impact of these marketing improvements upon the diffusion of new sorghum technologies.

In May, Gebisa Ejeta asked Sanders to participate in a training workshop for Ethiopian extension agents involved in a project to disseminate new sorghum cultivars in Ethiopia with resistance to *Striga* and associated technologies (inorganic fertilizer and water-retention techniques). This project was funded by the USAID Disaster Relief Office since it was a response to the regionalized famine problems in the drylands of Ethiopia in 2000. Sanders made a presentation on the economics of sorghum technology introduction and interacted with the workshop participants during the four-day seminar. He also consulted with various EARO economists during this stay in Ethiopia.

Research Investigator Exchanges

In the workshop in Mali of May 2002, we began working with Ouendeba Botorou , director of the millet network for West and Central Africa, on a marketing project to facilitate the new millet-processing entrepreneurs in obtaining a regular supply of high-quality white sorghums from a number of cooperatives in four Sahelian countries. We plan to provide field support for estimating farmer incomes and the contributions from various marketing innovations to the incomes of these farmers. This will lead to an ICRISAT project proposal by the end of 2002 for an expanded marketing research project to encourage and facilitate the production and marketing of the higher food quality millets.

Publications and Presentations

Book Chapters, Book Reviews, and Proceedings

Shapiro, Barry I., and John H. Sanders. 2002. "Natural Resource Technologies for Semiarid Regions of Sub-Saharan Africa," Ch. 20 in C.B. Barrett, F. Place, and A.A. Aboud (eds.), Natural Resource Management in African Agriculture: Understanding and Improving Current Practices, pp.261-264. New York, NY: CABI Publishing

Sanders, John H., and Mohamed Ahmed. 2001. "Developing a Fertilizer Strategy for Sub-Saharan Africa" Ch. 16 in Sustainability of Agricultural Systems in Transition, ASA Special Publication No. 64, pp. 173-184. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Sanders, John H., 2001. "Another World Food Scare?" Review of John Manning, Food's Frontier: The Next Green Revolution. North Point, NY: Farrar, Straus and Giroux. *Science* 291:1707-1708.

Dissertations and Theses

Abdoulaye, Tahirou A., "Farm Level Analysis of Agricultural Technology Change: Inorganic Fertilizer Use on Dryland in Western Nigeria," Ph.D., 2002.

Presentations

John H. Sanders, "Principal Results of the IGAD Study of New Technology Introduction into the Drylands of the Horn Countries and Implications for Future Projects," presented to the IGAD/REDSO/INTSORMIL six-country workshop to review the two-volume report of the team of consultants, Nairobi, Kenya, November 2001.

John H. Sanders, "Constraints and New Technology Development in the Sahel," presented to the Experts Committee meeting organized by ICRISAT and CFC, Bamako, Mali, April 2002.

John H. Sanders, "The Role of INTSORMIL in Agricultural Development in West and Central Africa," presented to the Experts Committee meeting organized by ICRISAT and CFC, Bamako, Mali, April 2002.

John H. Sanders, "The Economics of New Sorghum Technology Introduction," presented to the Workshop on the Diffusion of New Sorghum Cultivars with *Striga* Resistance, Nazareth, Ethiopia, May 2002.

Cropping Systems to Optimize Yield, Water and Nutrient Use Efficiency of Pearl Millet and Grain Sorghum

Project UNL-213
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Summary

Principal investigators in INTSORMIL Project UNL-213 continue with international research efforts related to nutrient management and use efficiency in West Africa and Central America. Preliminary pearl millet grain yield responses to microdose fertilizer application have been mixed, while larger basal fertilizer applications increased grain and stover yield of both population hybrids and local varieties. Research showed that an animal traction zaï system produced similar yield to the traditional zai system, but required 22 man-hours less labor per hectare. In Central America, nitrogen application increased sorghum grain yields quadratically for both photoperiod sensitive and insensitive varieties. Little difference in nitrogen use efficiency was found among the photoperiod insensitive varieties tested, indicating that broader screening of germplasm in Central America sorghum breeding programs will be needed to identify and develop high nitrogen use efficient sorghum varieties.

Research in the United States indicates that pearl millet has low yield potential in the Great Plains and is not a viable alternate crop except in late planting situations, such as double cropping and as an emergency replant crop. Study of "old" and "new" maize and sorghum hybrids indicate that maize had higher yield potential than sorghum in 1960, and that maize grain yield has increased more rapidly than grain sorghum for both dryland and irrigated situations. Plant breeding programs must increase sorghum grain yield potential to maintain or increase sorghum's role in Great Plains agriculture.

INTSORMIL Project UNL-213 emphasizes capacity development through graduate education, short-term training,

and coordination of the Central America Regional Program. Graduate students from Burkina Faso, Niger and the U.S. are completing degrees, and the lead Principal Investigator organized the Central America Sorghum Research and Planning Conference held in February 2002.

Objectives, Production and Utilization Constraints

Objectives

- Implement multi-year research on microdose, N and P fertilizer application on pearl millet grain yield, nutrient removal, and changes in soil nutrient levels in Burkina Faso, Mali and Niger.
- Implement research on mechanized zaï production system for pearl millet in Burkina Faso, weed control interactions with fertilizer rates in Mali, and fertilizer rate by plant population for hybrid grain sorghum seed production.
- Conduct research on adaptation, production practices, and grain quality for population hybrids in West Africa.
- Actively participate in the West and Central Africa Pearl Millet Research Network (ROCAFREMI) agronomic research and annual meetings in West Africa.
- Determine the planting date and row spacing recommendation for dwarf pearl millet hybrid production in eastern and western Nebraska.
- Evaluate grain sorghum and maize hybrid from the 1950s, 1970s and 1990s under low and high water holding capacity soils, wide and narrow rows, and dryland and irrigated environments.
- Conduct N rate and N use efficiency studies for grain sorghum production in El Salvador and Nicaragua.
- Increase research human capital in West African countries where pearl millet is an important crop through graduate education, short-term training, mentoring former students upon return to their home country, and active participation in the West and Central Africa Pearl Millet Network.
- Collaborate with national extension services and NGO/PVOs in transferring improved pearl millet agronomy practices.

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher pearl millet and sorghum grain and stover yields. This involves systems which increase nutrient and water availability to growing crops, and produces desired uniform stands. Present efforts emphasize crop rotation, intercropping, inorganic and organic fertilizer management, and residue management interactions with traditional and improved cultivars. These cropping systems research efforts require long-term investments of well-trained, interested scientists and stable funding. Education of additional scientists in crop production and continued support of their work after return to their home countries is needed to improve productivity of cropping systems and to maintain the soil/land resource.

Research Approach and Project Output

Pearl millet and grain sorghum are usually grown in stressful environments with high temperatures, lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length. Lack of water is usually considered to be the most critical environmental factor controlling growth and limiting yield in Africa, but a source of nitrogen and/or phosphorus often is more critical. This is especially true for intensive cropping systems using improved cultivars on degraded land. Nutrient use and water use efficiencies are closely interwoven with higher yields possible with improved cropping systems utilizing improved cultivars. Since human capital for research and extension activities are very limited for pearl millet producing areas in West Africa, project activities are generally conducted as either graduate education programs for scientists from this region, mentoring collaborative activities upon return of former graduate students, or collaborating with pearl millet research network (ROCAFREMI). Studies have been initiated with new collaborators in Central America on nitrogen fertilizer management and identification of nitrogen efficient genotypes for grain sorghum production which is also a critical issue in the region. In the U.S. Great Plains, production practice recommendations for planting date, nitrogen rate and water supply for high yielding, dwarf hybrids are being determined to help adoption as an alternate grain crop. This complex interaction of water, nitrogen, phosphorus, cultivars and yield enhancing production practices is the focus of Project UNL-213s research efforts.

Domestic (Nebraska)

Water Supply Effect on Pearl Millet Grain and Stover Yield (Nouri Maman, Ph.D. Thesis)

Research Methods

The experiment is being conducted on a Keith silt loam under a linear move irrigation system with drop nozzles at the High Plains Agricultural Laboratory located at Sidney, NE (west) in 2000 and 2001. The experiment was conducted using a randomized complete block design with a factorial (2 x 4) treatment arrangement and three replications. Factor 1 was the pearl millet hybrid (68A × 086R) and one grain sorghum hybrid (DK 28E). Factor 2 was composed of 4 different water regimes. The water regimes consisted of; (i) Control, rainfed; (ii) Full water supply at all growth stages (apply water to bring soil moisture level to 80% field capacity any time it falls to 70% field capacity); (iii) Water supply at boot stage, and (iv) water supply at grain fill stage. Soil water was measured using neutron probes. Grain and stover yields were collected at harvest, and seasonal grain and biomass water use efficiencies (WUE) were calculated. A similar study was conducted at Mead, NE (east) using a furrow irrigation system. Data were analyzed using analysis of variance procedures.

Research Results

At Sidney no rainfall occurred during the 2001 growing season, thus extremely low grain and stover yields of both pearl millet and grain sorghum were produced (Table 1). In 2002, Sidney produced higher yields with good rainfall, and in Mead in both years the grain yields were greater than at Sidney as the result of higher water holding capacity and a less stressful environment. No crop by water regime interaction occurred, thus the response of both crops to water regime were similar. Grain sorghum produced higher yield than pearl millet in all production environments, indicating limited potential for pearl millet as a new alternate grain crop. Full irrigation increased the average grain yield of the crops by 1.0 to 3.5 mg ha^{-1}. Partial irrigation increased yield, but to a lesser degree than full irrigation. Partial irrigation at the grain-fill stage increased grain yield more than irrigation at the boot stage. Yield component analysis indicated that water regime only had an influence on panicles/m^2 and kernels/panicle in the most stressful production environment of Sidney in 2000. Kernel weights were increased with single irrigation at mid-grain fill and with full irrigation. No one yield component stood out as being more important in yield determination than the others. At Sidney, the crops used similar amounts of water in both years, but grain sorghum had a 3 to 7 kg grain/mm higher grain water use efficiency. The biomass water use efficiencies were similar for the two crops in 2001, while grain sorghum had a 5 kg dry matter/mm higher biomass water use efficiency in 2000. Grain sorghum produced a higher yield and had higher water use efficiencies than pearl millet in these diverse production environments, thus without a large boost in yield potential, pearl millet has little potential as a crop in Nebraska.

Nitrogen Response of Pearl Millet
(Nouri Maman, Ph.D. Thesis)

Research Methods

The pearl millet hybrids 68A×086R and 293×086R were planted in randomized complete block experiments with side-dress nitrogen fertilizer rates of 0, 45, 90 and 135 kg ha^{-1} and four replications in 2000 and 2001. The study was conducted in Sidney, NE (west) on a Keith silt loam soil with approximately 100 kg ha^{-1} residual nitrate-nitrogen and in Mead, NE on a Sharpsburg silty clay loam soil with approximately 25 kg ha^{-1} residual nitrate-nitrogen. Leaf nitrogen concentration, leaf chlorophyll concentration, grain and stover yield, and plant nitrogen uptake were collected. Data were analyzed using analysis of variance, and nitrogen response using single-degree orthogonal contrasts.

Research Results

Pearl millet grain yields were quite low at Sidney in 2000, intermediate at Sidney in 2001 and high at Mead in both years. The yield levels corresponded to the total season rainfall and distribution during the growing season. Nitrogen fertilizer application increased grain yield linearly at Sidney (from 1.17 to 1.54 mg ha^{-1} in 2001 and 2.8 to 4.0 mg ha^{-1} in 2002) and Mead (from 2.5 to 4.0 mg ha^{-1}) in both years, indicating that more than 120 kg ha^{-1} was required to maximize pearl millet grain yield in these environments. Although pearl millet is a N use efficient species, relatively high N rates are required to optimize grain yield production.

Planting Date and Row Spacing of Pearl Millet
(Siebou Pale, M.S. Thesis)

Research Methods

Studies were conducted between 1995 and 2001 to determine recommended planting date and row spacing for pearl millet hybrids was conducted on a silty clay loam and sandy soil site in Mead, NE (east), a loam soil in Sidney, NE (west), and a sandy soil site in Ogallala, NE (west-central). Sidney has low rainfall, short growing season. and efforts are being made to intensify wheat-fallow production systems by incorporating pearl millet as a summer annual crop in this region. The pearl millet hybrids 68A×086R responses to planting date, and narrow (38 to 50 cm) and wide (76 cm) row spacing were compared to the grain sorghum check DK28.

Research Results

Measuring air or soil heat units gave better recommendations than using day of year or soil temperature. Pearl millet planting time between 239 and 501 air or 236 and 529 soil heat units optimized yield in eastern Nebraska, while in

Table 1. Effect of water regime on pearl millet and sorghum grain yield and yield components at Sidney and Mead, NE in 2000 and 2001. Since no crop by water regime interaction occurred, data are averaged across crops.

Water regime	Grain yield			Panicles			Kernels/Panicle			Kernel weight		
	Sidney 2000	Sidney 2001	Mead	Sidney 2000	Sidney 2001	Mead	Sidney 2000	Sidney 2001	Mead	Sidney 2000	Sidney 2001	Mead
	Mg ha^{-1}			No./m^2			No./Panicle			mg/kernel		
Rainfed	1.4	3.6	5.0	12.3	21.1	22.0	1226	1921	1859	9.8	15.1	16.8
Boot Irrigation	2.7	4.1	5.5	22.5	20.7	22.0	1275	2028	1826	10.4	15.5	17.6
Grain Fill Irrigation	3.0	4.6	5.8	17.5	19.6	22.0	1521	1933	1992	14.7	17.0	17.8
Full Irrigation	4.9	5.5	6.0	25.8	20.8	20.8	1902	2135	1972	13.0	17.0	18.2
	F>P											
Water Regime	<0.01	<0.01	<0.01	<0.01	NS	NS	<0.01	NS	0.04	<0.01	<0.01	<0.01
Contrasts												
Rainfed vs Irrigation	<0.01	<0.01	<0.01	<0.01	NS	NS	<0.01	0.04	NS	0.02	<0.01	<0.01
Full vs Partial Irrigation	<0.01	<0.01	0.01	0.07	NS	NS	0.03	NS	NS	<0.01	<0.01	NS
Boot vs Grain Fill	<0.01	<0.01	0.04	<0.01	NS	NS	NS	NS	0.02	NS	0.01	NS

western Nebraska, where elevation limits the growing season length, early planting at approximately 120 air or soil heat units was best. Pearl millet had a later planting time than sorghum even though pearl millet has a lower base temperature, and both crops had large planting time windows allowing flexibility in planting time without sacrificing yield. Pearl millet had 1.0 to 1.2 Mg ha^{-1} greater yield than grain sorghum when planted in late June or July, indicating that it has potential for replant or double crop situations. However, grain sorghum out-yielded pearl millet by 0.57 to 2.32 Mg ha^{-1} for normal planting dates in May and early June, thus grain sorghum is usually a more economical crop option than pearl millet.

Row spacing response was similar across locations, planting dates and the two crops. Narrowing rows from 76 to 38 cm increased the yield of both crops by 8 to 14% across the 15 year-location combinations in the study. Pearl millet and early-season sorghum producers should plant these crops in narrow rows to optimize grain yield production.

Grain Sorghum - Maize Hybrid Comparisons in Dryland and Irrigated Environments (Delon Kathol, M.S. Thesis)

Research Methods

A three-year study was initiated in 1999 to determine the importance and physiological basis for shift in dryland sorghum production to maize production in eastern Nebraska. Best hybrids were identified from the 1950s, 1970s and 1990s and produced in four environments each year. The environments are sandy loam and silty clay loam soil types, 76 and 38 cm row spacing, and irrigated and dryland water regimes. Grain yield and yield components, dry matter and leaf area, lodging and climatic data are being collected. Path correlation analysis will be used to identify relationships between grain yield and yield components, and stability analysis used to help identify crop/hybrid responses.

Research Results

Across years and production situations, altering row spacing had little effect on grain yield of both crops and crop-by-production condition interactions did not occur. In both years, hybrid within crop effects occurred ($P \leq 0.05$) and did not interact with the production situations used in the study. Averaged across five production situation-year combinations, sorghum yields increased from 6.8 for the 1950 hybrid to 7.05 mg ha^{-1} for the three 1970 hybrids to 7.5 mg ha^{-1} for the four 1990 hybrids, which suggests an increase in sorghum grain yield of 0.13 to 0.23 mg ha^{-1} /decade. Average maize hybrid grain yields increased from 8.55 mg ha^{-1} for the 1950 hybrid to 9.9 mg ha^{-1} for the three 1970 hybrids to 10.7 mg ha^{-1} for the four 1990s hybrids, which suggests an increase in maize yield of 0.68 to 0.4 mg ha^{-1} /decade. These data indicate that maize had higher grain yield potential than sorghum in the 1950s, and that maize grain yield has increased more rapidly than for grain sorghum.

International

Microdose Fertilizer Study (Burkina Faso, Mali and Niger)

Research Methods

Three-year central studies were initiated on-station in Burkina Faso (pearl millet), Mali (pearl millet on sandy and heavy soil, and grain sorghum on heavy soil) and Niger (pearl millet) in 2001. A randomized complete designed study was used with four replications. Treatments consisted of zero, microdose (cap full of complete fertilizer in the seed hill at planting), micodose + 20 kg ha^{-1} P, microdose + 40 kg ha^{-1} P, microdose + 30 kg ha^{-1} N, microdose + 60 kg ha^{-1}, microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N, and microdose + 40 . $^{-1}$ P + 60 kg ha^{-1} N. Each plot was sampled prior to initiating the experiment so that soil nutrient levels after three-years could be determined. Grain and stover yield, and N and P uptake in the grain and stover were collected. In addition, satellite studies were conducted on farms using zero, microdose and microdose + 20 kg ha^{-1} P + 40 kg ha^{-1} N treatments. One replication was planted per farm, and in the data analysis farms were considered to be replications.

Research Results

Preliminary results indicated that the yield increase due to microdose fertilizer application was not uniform across locations in the three countries, nor between station and on-farm sites. (Table 2). Microdose fertilizer application increased yield on-station in Niger and on a sandy soil in Mali, while no yield increase was in Burkina Faso nor on a heavy soil in Mali. The response on-farm was present in Burkina Faso, but not in Niger. Response to additional P and N application was also variable across countries, with Niger showing greater response to N, Burkina Faso to P, Mali sandy soil to combination of N and P, and no response to fertilizer on the Mali heavy soil. This study will be continued for two more years to document crop yield response and consequent changes in soil nutrient levels.

Population Hybrid by Production Environment Study (Cooperative with INTSORMIL Project ARS-213 - Burkina Faso, Mali, and Niger)

Research Methods

A randomized complete block designed study to evaluate a pearl millet population hybrid produced by INTSORMIL project ARS-213 with the best local variety under low and high yield environments was conducted in Cinzana (Mali), SARIA (Burkina Faso) and three locations in Niger in 2000 and 2001. The low yield environment consisted of no fertilizer with pearl millet planted in hills with 0.8m x 0.8m spacing. The high yield environment consisted of 23 kg ha^{-1} nitrogen, 20 kg ha^{-1} phosphorus and planting in hills with 0.8m x 0.4m spacing, except in Niger in 2000 where the hill

Table 2. Microdose, and N and P application influence on pearl millet grain yield in Burkina Faso, Mali and Niger in 2001.

	On-Station										On-Farm (7 to 10 Farms/Country)			
	Niger		Burkina Faso		Mali (Sandy)		Mali (Heavy)		Average		Niger		Burkina Faso	
Treatment	Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain	Biomass
	Mg /ha													
Zero	0.52	4.1	0.58	1.5	0.39	1.4	0.37	1.6	0.47	2.2	0.31	2.7	0.34	1.1
Microdose	0.64	6.3	0.53	2.2	0.61	3.0	0.27	1.3	0.51	3.2	0.33	3.4	0.56	2.3
Microdose + 20 kg/ha P	0.77	6.8	0.83	2.3	0.67	3.1	0.57	1.8	0.71	3.5				
Microdose + 40 kg/ha P	0.46	5.3	0.84	2.5	0.77	4.3	0.14	1.1	0.55	3.3				
Microdose + 30 kg/ha N	0.94	8.6	0.63	1.9	0.64	3.3	0.20	1.7	0.60	3.9				
Microdose + 60 kg/ha N	0.98	8.8	0.74	2.2	0.68	3.4	0.21	1.4	0.65	4.0				
Microdose + 20 kg/ha P + 30 kg/ha N	0.90	8.4	0.85	2.8	0.96	4.4	0.28	1.9	0.75	4.4	0.46	4.7	0.77	3.3
Microdose + 40 kg/ha P + 60 kg/ha N	0.98	8.4	1.08	2.7	0.89	5.3	0.36	2.0	0.83	4.6				
Probability	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.03	<0.01	<0.01
C.V. (%)	25	19	24	12	22	22	66	30			37	42		

Table 3. Grain and stover yield of the pearl millet population hybrid WA13 and a local variety in Burkima Faso, Mali and Niger in 2000 and 2001.

A. Grain yield		2000			2001				
Genotype	Production environment	Burkina Faso	Mali	Niger	Burkima Faso	Mali	Niger-Kalapati	Niger-N'Dounga	Mean
		Kg ha^{-1}							
WA13 (Population Hybrid)	Low	351	287	465	489	348	355	410	386
	High	617	517	577	834	338	650	469	572
Local	Low	497	767	872	597	723	82	156	528
	High	843	1112	673	1094	650	320	266	708

B. Stover yield		2001				
Genotype	Production environment	Burkina Faso	Mali	Niger - Kalapati	Niger - N'Dounga	Mean
		Kg ha^{-1}				
WA13 (Population Hybrid)	Low	832	1354	3184	3941	2328
	High	3358	1615	4020	5059	3513
Local	Low	1672	2383	1066	1309	1608

spacing remained constant. Data were analyzed using analysis of variance procedures.

Research Results

Grain yields were low in all cases, largely due to poorly distributed low seasonal rainfall in all locations in both years. The local pearl millet variety produced higher grain yield than WA13 in all three locations in 2000, and in Burkina Faso and Mali in 2001 (Table 3). The population hybrid produced higher grain and stover yields at the two locations in Niger in 2001, and appears to be better adapted to these production environments. The application of fertilizer and increasing plant population increased grain yield by 34 to 48%, and stover yield by 51 to 94% in these low-yield production situations.

Mali Weed Control Study

Research Methods

A randomized complete block designed experiment to evaluate the interactive effects of planting date, pearl millet genotype and hand weeding method on pearl millet grain and stover yield was initiated at Cinzana, Mali in 2000. Planting dates were early June and late June, varieties were India na 05 and Sanioba and six hand weed control methods (weed free, in-row weeding, between row weeding, in-row with soil ridging, in-row with mulching, and weedy check). Data were analyzed using analysis of variance procedures.

Research Results

Neither date of planting nor variety had a significant effect on pearl millet grain yield, although the later planting date tended to produce slightly more grain in 2000. Weeding method significantly affected both grain and stover yield with complete weeding or weeding in-row resulting in the greatest yield, between row and in-row with ridging or mulching resulting in intermediate yields, and the weedy check producing the lowest yield.

Mali Cover Crop Research
(Minamba Bagayoko)

The species *Dolicos lablab*, *Fava larga*, *Canvalia ensiformis*, *Crotalaria juncea*, *Stizolobium deeringieanun*, *Crotalaria espectabilis*, *Stizolobium aterrimum*, *Cajanus* *cajan*, and *Crotalaria breviflora* were grown at the Cinzana Research Station to produce seed for future studies and provide initial evaluation as a dry season cover crop. Limited rainfall did not allow adequate production of seed, which is being repeated in 2002. Observations indicated that *Dolicos lablab* and *Canavalia ensiformis* grew well and protected the soil during most of the dry season.

Mechanized Zaï Research (Taonda Jean Baptiste)

Research Methods

The traditional zaï system composed of planting pearl millet seed in a small hole with a small amount of manure increases water infiltration on some soils and results in increased yield, but requires considerable land labor. Scientists at INERA have developed a mechanized zaï using animal traction. The objective of this study was to determine the effectiveness of the mechanized zaï to the traditional zaï and a flat-planted control across six different soil types in Burkina Faso. The study was conducted on 12 farms in three villages with each farm considered a replication. The soil types present on the farms was sandy, sandy loam, sandy clay, clay, gravelly clay and gravel.

Research Results

Pearl millet grain yields were over 1.0 mg ha^{-1} on the sandy and clay soil, approximately 0.7 mg ha^{-1} on the sandy clay, gravelly clay and gravelly soil, and 0.4 mg ha^{-1} on the sandy loam soil, but no interaction between soil type and planting method was found. The traditional and mechanical zaï produced similar grain and stover yields, which were more than 0.4 mg ha^{-1} more grain than the control and more than 1.4 mg ha^{-1} more stover. The mechanized zaï has potential to produce the yield advantage associated with the traditional zaï system through use of animal traction, but with greatly reduced labor and economic cost. The manual zaï system requires approximately 300-man hours of labor/ha while the mechanized zaï requires approximately 22 man hours/ha.

Production Practices for Hybrid Sorghum Seed Production (Seyni Sirifi)

Research Methods

A study was initiated in Lossa, Niger to determine recommended plant populations and nitrogen application rates for seed production of the sorghum hybrid NAD-1. The female inbred hybrid was planted at four plant populations and four nitrogen rates. Date of flowering, plant height and grain yield data was collected.

Research Results

Preliminary results indicate that hybrid seed production increased linearly with increasing nitrogen application, while plant population had little effect on the seed yield due to the female lines tillering ability. This research will be continued.

Central America Nitrogen Use Efficiency Studies (Wilfredo Castaneda, Leonardo Garcia and Orlando Tellez)

Research Methods

A two-year study was conducted at two locations in El Salvador and two locations in Nicaragua with the objective to determine if differences in nitrogen use efficiency between commonly used photoperiod sensitive and insensitive sorghum varieties and optimal nitrogen fertilizer rates for grain sorghum production, and to identify high nitrogen use efficient varieties. At each location a factorial combination of four (photoperiod insensitive) or six (photoperiod sensitive in El Salvador) grain sorghum varieties were grown with four nitrogen fertilizer rates in a randomized complete block design with four replications. Grain and stover yield, and N concentration of grain and stover at harvest were collected in 2001 to allow determination of nitrogen use efficiency. Data analysis was done using analysis of variance procedures, and orthogonal contrasts determined for nitrogen rate response.

Research Results

Among the photoperiod insensitive varieties only small differences in grain, biomass and fertilizer nitrogen use efficiency were found (Table 4), and it was concluded that screening of a broad base of germplasm used in breeding programs in El Salvador and Nicaragua would be needed to identify and develop varieties with high nitrogen use efficiencies. Nitrogen removal by sorghum plants was closely associated with whole plant yield (grain plus stover). Grain yield differences among sorghum varieties in El Salvador was only 0.6 (18% - 2000) or 0.7 mg ha^{-1} (20% - 2001). Similar differences among varieties were found in Nicaragua in 2001 (25%) but larger differences occurred in 2001 (41%). The variety INTA -2001 produced high grain and stover yields across years and locations in Nicaragua.

Among the photoperiod sensitive varieties, SCP-805 produce the highest grain yield and grain nitrogen use efficiency, while it produced less stover resulting in an intermediate biomass nitrogen use efficiency. The varieties Santa Cruz, Limay and Yalaguina produced high stover yields and low harvest indices. The variety ES-790 had a very high fertilizer nitrogen use efficiency, suggesting this variety is a good choice in low yield situations in which only small amounts of fertilizer are to be applied.

Grain sorghum yields usually responded to increasing nitrogen application rates in a quadratic manner, and seldom was yield maximized by the highest rate used. In El Salvador, 115 kg ha^{-1} nitrogen increased grain yield of photoperiod insensitive sorghum varieties from 2.5 to 4.5 mg ha^{-1} while 115 kg ha^{-1} nitrogen in Nicaragua increased yield from 2.5 to 3.9 mg ha^{-1} . Photoperiod sensitive sorghum relay intercropped with maize in El Salvador increased yield from 1.8 to 3.0 mg ha^{-1} with application of 95 kg ha^{-1} nitrogen. These impressive yield increases resulting

Table 4. Yield, N removal and N use efficiency for photoperiod sensitive and insensitive grain sorghum varieties in El Salvador and Nicaragua in 2000 and 2001. Data are averaged over four N application rates and two locations. Fertilizer N use efficiency for the lowest N rate of 47 kg ha^{-1}.

	2000	2001					
		Yield			N Use Efficiency		
	Grain	Grain	Stover	N Removal	Grain	Biomass	Fertilizer
	- - - - - - - - - - Mg ha^{-1} - - - - - - - - - -			Kg ha^{-1}	- -Kg DM/kg N - -		%
Photoperiod Insensitive							
El Salvador:							
Soberano	3.8	4.1	3.0	82	51	90	35
INTA-2000	3.4	4.0	3.8	86	46	90	44
CENTA RCV	3.5	3.7	3.0	72	52	94	56
INTA-2001	4.0	3.4	3.5	67	51	103	42
Nicaragua:							
CENTA RCV	3.2	3.1	7.9	93	34	118	
INTA-2000	4.5	3.5	6.0	85	41	111	
Pinolero 1	3.8	2.8	7.3	77	36	131	
Tortillero Precoz	3.5	2.8	4.4	69	41	104	
Photoperiod Sensitive							
***El Salvador*:**							
86-EO-226	2.4	3.4	5.4	75	45	117	15
Santa Cruz	0.5	1.3	7.5	81	17	110	47
SCP-805	2.7	4.0	5.2	82	49	112	49
Limay	1.6	2.7	7.4	95	28	107	70
ES-790	2.5	3.6	6.0	89	41	109	129
Yalaguina	0.7	1.2	6.6	61	20	128	38

from nitrogen application are being tested on farmers fields in 2002.

Networking Activities

Workshops

INTSORMIL Central America Regional Program Research Results and Planning Workshop, Managua, Nicaragua, 27 - 28 February, 2002.

American Society of Agronomy Meetings, Charlotte, NC, 21-25 Oct., 2001.

Scientific Liaison Officer Workshop, USAID, Washington, D.C., 20-21 June, 2002.

Research Investigator Exchange

Pale Siebou (Burkina Faso) completed his M.S. degree (May 2002) and Nouri Maman (Niger) and Delon Kathol (U.S.A.) will complete degrees in the coming year.

Hosted visiting scientists Aildson Duarte, University of São Paulo, College of Agriculture (ESALQ) Piracicaba (SP), Brazil.

Research Information Exchange

Funds passed through to Burkina Faso, Mali and Niger to assist with collaborative research.

Visited INTSORMIL research efforts in El Salvador and Nicaragua in November, 2001.

Scientific Liaison Officer to the Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Publications and Presentations

Abstracts

Pale, S., S.C. Mason, T.D. Galusha, D.J. Lyon, R.N. Klein and R.K. Higgins. 2002. Planting time for pearl millet in Nebraska. Agron. Absts.

Mason, S.C., S. Pale and T.D. Galusha. 2002. Pearl millet row spacing recommendations for Nebraska. Agron. Absts.

Galusha, T.D., N. Maman, S.C. Mason and D.J. Lyon. 2002. Pearl millet and sorghum yield and water use efficiency in eastern Nebraska. Agron. Absts.

Maman, N., D.J. Lyon, S.C. Mason and R.K. Higgins. 2002. Timing of water application on pearl millet and sorghum yields in western Nebraska. Agron. Absts.

Kathol, D., S.C. Mason and T.D. Galusha. 2002. Yield components of new and old maize and sorghum hybrids. Agron. Absts.

Journal Articles

Samba Traoré, J. L. Lindquist, S. C. Mason, A. R. Martin, and D.A. Mortensen. 2002. Comparative ecophysiology of grain sorghum *(Sorghum bicolor) and Abutilon theophrasti* in monoculture and in mixture. Weed Res. 42: 65 - 75.

Masek, T.J., J.S. Schepers, S.C. Mason and D.D. Francis. 2001. Use of precision farming to improve application of feedlot waste to increase nutrient use efficiency and protect water quality. Commun. Soil Sci. Plant Anal. 32:1355-1369.

Soil and Water Management for Improving Sorghum Production in Eastern Africa

Project UNL-219

Charles Wortmann and Martha Mamo
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Summary

Activities to date have addressed the INTSORMIL objectives of increased yield and improved institutional capacity. Collaborating researchers in Ethiopia are working with farmers to address production constraints associated with water deficits and low soil fertility. Tillage and implement options are being tested at various semi-arid sorghum production areas in Ethiopia. Tillage effects on organic matter and soil physical properties are being assessed for improved soil water management. In eastern Nebraska, soil fertility management options are being evaluated including the use of starter fertilizers for no-till situations and the rotation effect of soybean on sorghum N nutrition. P availability indices are being fine-tuned for soils of Nebraska, Ethiopia and Mozambique.

An INIA researcher from Mozambique has started his Master's degree program on soil fertility management at the University of Nebraska. Two researchers are being recruited for Master's degree studies at Alemaya University in Ethiopia.

Objectives, Production and Utilization Constraints

- Initiate nutrient management and water conservation research, such as use of tie-ridging or micro-catchments, in two semi-arid areas in Ethiopia.
- Initiate on-farm trials and/or collaborate in on-going station trials to verify N credit to sorghum following soybeans.
- Begin research on starter fertilizers for no-till sorghum production in Nebraska.
- Initiate research to predict P fixation capacity of soils across Nebraska and Ethiopia and assess effect of tillage systems on organic matter and soil aggregation.
- Begin data compilation to evaluate internal nutrient use efficiencies, and relate variations in grain yield and seed number to plant N concentration, uptake, and N harvest index.
- Inadequate nutrient supply and water deficits are the primary production constraints addressed in this research.

Research Approach and Project Output

Work on each of the following was begun in 2002 and important findings are not yet available.

Nutrient and Water Management Research in Ethiopia

Preliminary research at three or four sites ranging in elevation from 1300 to 1800 m and with different soil types and cropping systems has been established in two semi-arid sorghum production areas of Ethiopia. The objectives are to obtain farmer and researcher assessment of tillage and implement options and to determine how tillage for water conservation interacts with nutrient supply and time of planting. The sites include Welench'iti, Mieso, and Mekele at Abergele with trials on three farms per site for both April and June planting. Main plot treatments include:

Traditional, e.g., tilled with *maresha*, broadcast sowing, and *shilishalo* for weed control.

In-furrow row planting with test planter and tie ridges made before planting with the modified *maresha*.

In-furrow row planting with test planter and tie ridges made at first weeding with the modified *maresha*.

Conservation tillage- reduced tillage. Plow 1-2 times. Apply Lasso Atrazine pre-emergence.

The split plot treatments are with and without fertilizer at the currently recommended rate. Farmer assessments of the technical options are considered as important as the agronomic observations.

Starter fertilizer for No-Till Sorghum Production in Nebraska

Starter fertilizer use has generally not been economical in Nebraska under tilled conditions. However, results from neighboring states indicate good potential for starter fertilizers under some no-till conditions. Starter placement, as well as inclusion of sulfur in the starter fertilizer, is being investigated under diverse no-till conditions to better determine when starter use will be economical. Three trials are conducted at different topographic positions/soil types on each of two farms with a total of 12 sorghum trials with 4 replications conducted over a 2-year period. All sites will be dryland. The eight treatments will include three placement options with the starter fertilizer formulations as either N+P or N+P+S. Observations are made on early growth and nutrient uptake, and on above-ground biomass and grain yield.

Soybean N credit Verified for Grain Sorghum

Currently a nitrogen credit of 45 lb/A is given to sorghum following soybean but the credit may be as much as 80 lb/A. The objective of this research is to verify a credit of 75 lb/A. Six on-farm trials have been established in Lancaster, Saunders and Gage counties across diverse topographic positions and soil types. All trials are under farmer management. Four N rates are evaluated with four replications per trial. Observations include days to flower, height, yield, and nutrient (N,P,K) uptake in whole plant and in grain.

P fixation

Phosphorus use efficiency will be improved by developing predictive methods for estimating P fixation capacity for soils of eastern Africa and Nebraska. Surface soil samples (0-15 cm depth) are being collected in Ethiopia, Mozambique and Nebraska. Phosphorus sorption indices are generated. Soil properties such as clay (texture), organic matter, calcium carbonate, and iron plus aluminum oxides levels will be related to P sorption indices for prediction of potential plant P availability and improved P recommendation.

Tillage and Organic Matter

Tillage effects on soil organic matter are being evaluated on soils from eastern African and Nebraska. The soil samples (0-5 cm depth) are collected from on-going tillage trials which have at least four years of continuous no-till as one treatment. Soils are sampled from the no-till as well as one or more tilled treatments. Tillage effects on organic matter fractions and aggregate stability are assessed.

Evaluation of Internal Nutrient Use Efficiency

Using data from trials conducted for other purposes and in diverse environments, internal nutrient use efficiency (uptake as well as metabolic use efficiency) by sorghum will be studied as a means to better understanding nutrient management for sorghum. It is expected that basic concepts of QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) will be useful in interpretation of the results. Data from several years and locations will be needed before conducting the analysis. Data compilation is underway.

Networking Activities

Technical and financial support, as well as equipment, has been provided to sorghum researchers in Ethiopia.

Publications and Presentations

Presentation

Soil and Water Management for Improving Sorghum Production, by Charles Wortmann and Martha Mamo presented to the Nebraska Sorghum Growers Board on June 11, 2002.

Germplasm Enhancement and Conservation

Breeding Pearl Millet with Improved Performance and Stability

Project ARS-204
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Summary

This project was initiated in January 2000. Population hybrids among West African land races were made in 1999 and in the greenhouse during the 1999-2000 winter. Cooperators were identified in Niger, Mali, Senegal, Zambia and Nigeria for testing and evaluation of pearl millet population hybrids among land races. Seeds were sent to all cooperators. Population hybrids were crosses among West African land races, but the hybrids did not out-yield the local genotypes, indicating a need to produce hybrids among locally adapted and desired types or at least where one parent is from this group. SOSAT-C88 was identified as a parent with good general combining ability that tended to produce the highest yielding grain hybrids. Significant variation existed among the population hybrids for grain yield. Only small differences for grain yields were observed for the various cycles of the population hybrids. However, forage yields of cycles 2 and 3 were significantly lower than for cycle 1. Significant differences were observed for downy mildew resistance among the population hybrids. The population hybrids appear to have potential for improving grain yields in West Africa. One population hybrid, WA13, produced more grain and fodder in Niger than the best local genotype.

Plans are to release a dwarf grain hybrid, TifGrain 102, developed in the Georgia program.

Objectives, Production and Utilization Constraints

Objectives

West Africa

- Improve the productivity and stability of pearl millet cultivars.
- Provide short- and long-term training for pearl millet breeders.

U.S.

- Use West African germplasm to improve germplasm and productivity of U.S. Hybrids.

Constraints

Constraints in West Africa include moisture, availability of fertilizers, resources to purchase fertilizer and other inputs, pest damage (insects, diseases, weeds, and birds), low yields, unstable markets, etc. Plant breeding can help to provide genetic resistance to pest, improve yields, and improve stability of yields. These genetic improvements due to plant breeding can have long-term recurring benefits.

Research Approach and Project Output

Land races from West Africa were assembled and grown under quarantine. Land races were intercrossed by collecting pollen from about 300 plants of one land race, bulking the pollen and using the bulked pollen to pollinate 300 plants of another land race. These crosses are cycle 1 and are referred to as population hybrids (Tables 1 and 2). The same procedure was used to produce cycles 2 and 3, except that the pollen collection and crossing were conducted on 300 random plants within each cycle1 population hybrid. An open-pollinated (random mating) population of cycle 1 was also grown in 2001 for the Exbornu × Ugandi(WA31) and Exbornu × Mansori (WA32) crosses. These population hybrids were evaluated for grain yield in Niger, Nigeria, Senegal, Mali, and Zambia in replicated trials. The hybrids were evaluated for forage production as part of a 9 x 9 lattice trial

Table 1. Yields of population hybrids grown in Nigeria, Senegal, Mali and Zambia during 2001.

		Grain weight/plot		Grain/plot	Grain yield	Dry matter yields	Downy mildew[2]		
2001 Number	Pedigree	Nigeria g	Senegal g	Zambia kg	Mali kg ha^{-1}	Georgia kg ha^{-1}	Nigeria	Mali	Niger
WA 8	99-Ex-Borno Ugandi (C2)	1167	2125	0.478	1030	8410	5.0	6.3	8.4
WA 9	Ex-Borno × Mansori (C2)	917	2300	0.428	865	7607	3.7	9.1	13.9
WA 10	Ex-Borno × Iniari	800		1.023	925	7709	8.3	10.8	8.4
WA 11	Ex-Borno × P3Kolo	1133			1275	8989	3.3	3.4	7.0
WA 12	Ex-Borno × Ugandi	750	2613	0.955	1090	6573	1.3	12.5	22.2
WA 13	Ex-Borno × Mansori	950	2488	0.818	835	10291	5.0	17.1	16.7
WA 14	Ex-Borno × Iniari	1050		0.868	1045	9188	4.3	4.6	7.0
WA 15	P3Kolo × Ugandi	1133		0.885	910	7554	2.7	10.2	18.1
WA 16	P3Kolo × Mansori	967		0.890	1485	10285	6.3	2.9	9.7
WA 17	P3Kolo × Iniari	1067		0.750	1140	9143	3.3	4.6	16.7
WA 18	Ugandi × Mansori	983		0.993	1105	8805	5.3	17.6	7.01
WA 19	Ugandi × Iniari	667		0.715	820	8314	0.7	5.1	13.9
WA 20	Iniari × Mansori	650		0.725	1060	9538	2.3	7.4	5.6
WA 21	2000-Ex-Borno SOSAT-C88	1050	4200	1.093	1120	8570	1.0	8.0	4.2
WA 22	Mansori × SOSAT-C88	1150	3838	0.858	1120	10438	2.3	8.0	1.4
WA 23	SOSAT-C88 × Ankountess	1500	4488	1.298	1665	11571	3.3	1.2	1.4
WA 24	SOSAT-C88 × HKP-GMS	1483		0.863	1150	10515	0.0	9.7	11.1
WA 25	SOSAT × GR-P1	1600		1.095	1545	10669	2.3	2.8	2.8
WA 26	Ugandi × SoSat-C88	1200	3650	1.400	1215	8465	1.0	12.5	2.8
WA 27	Ex-Borno × Ugandi (C2)	617	2275	0.538	850	7398	8.7	11.4	11.1
WA 28	Ex-Borno × Mansori (C2)	683	2512	0.653	1075	7496	6.3	19.3	18.1
WA 29	Ex-Borno × Ugandi (C3)	983	2188	0.698	1065	7507	6.0	7.9	7.0
WA 30	Ex-Borno × Mansori (C3)	567	1881	0.998	850	6942	3.0	13.6	19.5
WA 31	Ex-Borno × Ugandi (C1-op)	967		1.138	1015	8402	6.7	11.4	13.9
WA 32	Ex-Borno × Mansori (C1-op)	917		1.243	950	9566	6.3	9.1	11.1
Check	Souna3		3350						
Check	SoSat				1575			8.0	
Check	SoSat-C88	867					2.7		
Check	Ex-Borno	1283					3.7		
Check	Toroniou C1				2620			12.5	
Check	Boboni				2305			24.4	
Check	Lubasi			0.880					
Check	CIVT								12.5
Check	CT6								11.1
Check	57007BR/W op			0.120					
Check	NCD2-HE op			0.703					
Check	Okahana-1			0.768					
Check	Kuomboka			1.270					
Check	Kataba Local			0.610					
Check	Tifleaf 3					13530			
CV %		32	20	29	28	17	75		
5 % LSD		520	645	.502	476[1]	2127	4.6	7.5	11.0

All WAs are cycle 1 population hybrids except as indicated,
WA 8, WA 9, WA 10, WA 27 and WA 28 are cycle 2
WA 29 and WA 30 are cycle 3
WA 31 and WA 32 are open-pollinated cycle 1.
[1]PPDS
[2]Number of plants per plot in Nigeria and % plants per plot in Mali and Niger.

Table 2. Performance of various cycles of the population hybrids in 2001.

		Dry matter		Country			
Cross	Cycle	Yield kg ha^{-1}	%	Senegal g/plot	Nigeria g/plot	Zambia g/plot	Mali g/plot
Exbornu × Ugandi							
WA 12	1	6573	16.6	1844	750	955	1090
WA 31	1 op	8409	14.6		967	1138	4015
WA 08	2	8410	14.1	1537	1167	478	1030
WA 29	3	7507	14.4	1537	983	698	1065
Exbornu × Mansori							
WA 13	1	10291	14.4	1737	950	818	835
WA 32	1 op	9566	14.2		917	1243	950
WA 09	2	7607	13.5	1575	917	428	865
WA 30	3	6942	14.9	1881	567	998	850
Exbornu × Iniari							
WA 14	1	9188	14.6		1050	868	1045
WA 10	2	7709	14.1		800	1023	925
LSD - 5%		2127	2.0	645	520	502	476

in Georgia. Population hybrids with SOSAT-C88 as a parent tended to perform better at almost all locations (Table 1). For example, hybrids WA 23 and WA26 were in the top four grain producers group at all locations. WA25 was in the top four at three of the four locations. A common parent of these hybrids was SOSAT-C88. It is interesting to note that WA 23 and WA25 also produced the most forage dry matter of the population hybrids. No population hybrid out-yielded the best local genotypes at any location except in Senegal where WA21 and WA23 produced significantly more grain. Performance of the various cycles of the population hybrids is summarized in Table 2. At most locations there were only small differences for grain yield among the various cycles indicating that hybrid vigor could be maintained in these population hybrids. An unexpected response was the grain yield of WA31 and WA32 in Zambia where these two open-pollinated progenies of cycle 1 tended to produce the most grain. This was not observed in either Nigeria or Mali and we have no explanation for this response. Forage yields were somewhat different for the cycles of the population hybrids. No significant differences were observed for cycles of the Exbornu × Ugandi and the Exbornu × Iniari crosses, but cycles 2 and 3 of the Exbornu × Mansori cross produced less dry matter than cycle 1 indicating genotype responses for yield stability in these population hybrids. Significant differences were recorded for downy mildew resistance among the population hybrids, both at a specific location and among locations. The least amount of variations and the lowest incidence of downy mildew was observed in Nigeria. Hybrids such as WA23 showed a low incidence of downy mildew at all three locations, whereas WA26 showed a low incidence in Nigeria but a higher level in Mali. This variation could be due to different races of the disease in the various countries. The population hybrids could make a contribution to improving grain yields of pearl millet in West Africa. However, it appears that crosses need to be made between specific types (maturity, height, grain color and size, head length, etc.) with local adaptation. Genotypes such as SOSAT-C88 with good general combing ability could be effectively used to enhance yield. Crosses between SOSAT-C88 and Souna3, Kuomboka, Toroniou C1 should be evaluated for grain production in Senegal, Zambia and Mali, respectively. The grain and fodder yields of WA-13 were evaluated at two fertility levels in Burkina Faso, Mali, and Niger in a cooperative study with project UNL-213. WA-13 appeared to be adapted to Niger conditions and performed much better than the local cultivar at both locations. WA13 also was one of the best forage producers in the Tifton, GA test. This part of the project is discussed further in the UNL-213 report. We have been working on a disease (mainly rust) resistant dwarf (1.5 m tall) pearl millet grain hybrid for about eight years. Plans are to release an advanced hybrid, TifGrain 102, at the end of 2002. TifGrain 102 yielded from 4300 to 5700 kg ha^{-1} for May and June plantings in 2001. Row widths of 35 to 52 cm appear to produce the most grain. The hybrid flowers in 45 days and grain can be combine harvested in 85 days.

Networking Activities

Sent 21 population hybrids to Nigeria and 13 population hybrids to Senegal.

Ferdinand Muuka, pearl millet breeder in Zambia spent three weeks in the Tifton,GA program.

Jurgens Hoffman from Namibia spent two days in Tifton, GA.

Other cooperating scientists

Ouendeba Botorou, ROCAFREMI Coordinator, ICRISAT Sahelian Center, Niamey, Niger.

Publications and Presentations

Journal Article

Sanogo, M.D. and W. W. Hanna. 2002. Effects of drying time and method on viability of stored pollen of pearl millet. International Sorghum and Millets Newsletter (accepted).

Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Biotic and Abiotic Stress

Project PRF-207
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Summary

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Research and germplasm development activities in PRF-207 attempt to address these essential requirements.

PRF-207 addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in some of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed.

In the last four years, research efforts in PRF-207 have focused on a selected core of constraints that limit the productivity and utilization of the sorghum crop. We conducted specific studies in attempting to understand the genetic and physiologic basis of drought tolerance using a mix of both traditional and molecular approaches. We also conducted several studies in elucidating the basis of grain mold resistance in low and high tannin sorghums. Specific studies were undertaken in determining the role of physical and chemical kernel properties associated with mold resistance, and in assessing the nature of specific phenolic compounds that contribute to grain mold resistance. We also conducted major studies on assessing genetic diversity using both phenotypic characters and molecular markers. The results of many of these experiments have been summarized in our previous reports. In Year 24, we summarized the results of our genetic diversity analysis on the Sudan sorghum collection.

Objectives, Production and Utilization Constraints

Objectives

Research

- Study the inheritance of traits associated with resistance to biotic and abiotic stresses in sorghum and/or millets.
- Elucidate mechanisms of resistance to these stresses in sorghum and/or millets.
- Evaluate and adapt new biotechnological techniques and approaches in addressing sorghum and millet con-

straints for which conventional approaches have not been successful.

Germplasm Development, Conservation, and Diversity

- Develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.
- Develop and enhance sorghum germplasm with increased levels of resistance to drought, cold, diseases, and improved grain quality characteristics.
- Assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U.S. and LDC scientists and institutions.
- Assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity or for discerning genetic diversity of sorghum and millet germplasm pools.

Training, Networking, and Institutional Development

- Provide graduate and non-graduate education of U.S. and LDC scientists in the area of plant breeding and genetics.
- Develop liaison and facilitate effective collaboration between LDC and U.S. sorghum and millet scientists.
- Encourage and facilitate positive institutional changes in research, extension and seed programs of collaborating countries involved in sorghum and millet research and development.

Research Approach and Project Output

Research Methods

The research efforts of PRF-207 are entirely interdisciplinary. The on-campus research at Purdue is in close collaboration with colleagues in several departments. We undertake basic research in the areas of biotic and abiotic stresses where a concerted effort is underway in elucidating the biochemical and genetic mechanism of resistance to these constraints. Field and laboratory evaluations of sorghum and millet germplasm are coordinated, the results from one often complimenting the other. In addition, there have been collaborative research efforts with colleagues in Africa where field evaluation of joint experiments are conducted.

Our germplasm development and enhancement program utilizes the wealth of sorghum and millet germplasm we have accumulated in the program. Intercrosses are made in specific combinations and populations generated via conventional hybridization techniques, through mutagenesis, or through tissue culture *in vitro*. Conventional progenies derived from these populations are evaluated both in the laboratory and in the field at West Lafayette, Indiana for an array of traits, including high yield potential, grain quality, as well as certain chemical constituents that we have found to correlate well with field resistance to pests and diseases. We also evaluate our germplasm for tropical adaptation and disease resistance during the off-season at the USDA Tropical Agricultural Research Center at Isabella, Puerto Rico. Selected progenies from relevant populations are then sampled for evaluation of specific adaptation and usefulness to collaborative programs in Sudan, Niger, and more recently Mali. Evaluation of the drought tolerance of our breeding materials have been conducted at Lubbock, Texas in collaboration with Dr. Darrell Rosenow, in a winter nursery at Puerto Vallarta, Mexico, as well as the University of Arizona Dryland Station at Yuma, Arizona. Over the years, assistance in field evaluation of nurseries has also been provided by industry colleagues particularly at Pioneer HiBred and DeKalb Genetics.

The training, networking and institutional development efforts of PRF-207 have been provided through graduate education, organization of special workshops and symposia as well as direct and closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali and some in Southern Africa through SADC/ICRISAT.

Research Findings

Analysis of Regional Diversity and Distribution among Sorghums of the Sudan

Sorghum originated in the Northeast quadrant of Africa over 3000 years ago, and slowly dispersed into other parts of Africa, eventually spreading its area of cultivation into Asia and the rest of the world. Diversity of sorghum appears to be highly correlated with duration of domestication and the type of farming practiced in a geographical area. A high level of diversity was reported in sorghums from Ethiopia, a primary center of origin, from India, a secondary center of domestication, as well as from China, another important center of diversity for sorghum.

Sudan is one of the most important centers of sorghum domestication and cultivation. Sorghum is grown in every region of the country where it is possible to raise a crop. Nearly 80% of the total grain production in the country is obtained from sorghum. It is the staff of life for all Sudanese. In many parts of the country the crop is wholly utilized. The grain is used for making *kisra* (unleavened bread from fermented dough), a local porridge, *asida,* a non-alcoholic beverage, *abreih*, and a local beer, *marisa*. The stalks are used as building material and the straw is utilized as animal feed or as source of fuel.

Sorghums from the Sudan have impacted sorghum improvement efforts globally. They have served as germplasm sources for improvements in yield, drought tolerance, stalk strength, insect and disease resistance, as well as nutritional quality. Early introductions of sorghum into the USA were primarily from Sudan. Sudan was probably the place where mutations for height and maturity took place in nature and where 'U.S. type sorghums' originated providing an excellent opportunity for gene transfer between tropical and temperate sorghums. Indeed many varieties such as *hegaris*, *feteritas*, *zerazeras* and *kurgis* have contributed much towards breeding of improved sorghum varieties in both the U.S. and India. In spite of their immense global importance, however, no organized diversity analysis has been reported on sorghums of the Sudan except for a few collection reports describing apparent variability among Sudanese sorghum landraces. The value of these collections is better appreciated if a thorough analysis of the genetic diversity is undertaken. We therefore, undertook an analysis of the Sudan sorghum collection to develop a better understanding of the diversity and distribution of the present collection and to provide a basis for formulating policy for future action.

A total of 2017 Sudanese sorghum landraces in the ICRISAT gene bank were included for this study. Passport information of accessions were designated either by scientists of the institute which transferred the material to ICRISAT, or by local farmers where the germplasm accession was collected. The collection was divided into three groups corresponding to the nature of the material, i.e., breeding lines, advanced selections, (both originating from Sudanese research institutes), or landraces. Only landraces were considered in the present study. Landraces collected from farmers' fields were designated with local names as well as localities and geographical coordinates (latitude, longitude and altitude) of the sampled fields. Accessions from local markets or those donated by individuals were described for passport data with local names occasionally, but primarily by the contributing institute's geographical location.

Upon entry into the gene bank at ICRISAT, international sorghum numbers (IS number) were assigned to each accession. Results from morphologic characterization and agronomic evaluation for each accession were recorded in the ICRISAT database. Morphologic characterization of accessions was conducted at ICRISAT over the last 20 years. Accessions were grown on a vertisol soil at ICRISAT Patancheru, India (17°25'N, 78°E) and characterized during the rainy and the post-rainy seasons. Longer day lengths, lower temperatures, and cloudy and rainy weather often characterize the rainy season. Only plant height (PHTK) and days to flowering (FLK) were recorded during the Kharif, long rainy season. During the Rabi, post-rainy season, data were recorded for eight quantitative characters, namely, plant height (PHTR), days to flowering (FLR), number of basal tillers (BT), panicle exsertion (PEX), panicle length and width (PLG and PWD), kernel size (KRS), and 100-seed weight (SWT). Additional data on 10 qualitative characters, including presence of nodal tillers (NT), plant pigmentation (PIG), glume color (GLC), midrib color (MRC), panicle compactness and shape (PCS), threshability (THR), glume covering (COV), kernel color (KRC), endosperm texture (TEX), and presence of subcoat (SC) were also recorded. Race classification of *Sorghum bicolor*, as proposed by Harlan and de Wet (1972) and defined by five races (Bicolor, Caudatum, Durra, Guinea and Kafir) and their 10 intermediates based on spikelet and panicle shape at maturity, was used to assess racial distribution.

Among the 2017 Sudanese sorghum landraces maintained at ICRISAT, only 45% were geo-referenced in the database with information on province and/or specific locality of origin . Gezira-Gedarif, one of the major irrigation schemes and large-scale mechanized sorghum farming areas of the world , is home to 73% of the geo-referenced landraces. Among landraces collected on-farm, 52.5% were from 20 different localities in the Blue Nile province. Upper Nile included fewer on-farm collections since all of the entries were designated as originating from Tozi, where an old rainland experiment station was located.

All the races except the Guinea-Kafir intermediate were present in the Sudan collection. Four landraces belonging to the subspecies *Sorghum drummondii* (an annual weedy species) were also present. Landraces belonging to the race Kafir, its intermediates Bicolor-Kafir and Durra-Kafir, and the intermediate Bicolor-Guinea were under represented in the Sudan collection. Race distribution in the Sudan collection was heavily skewed (80%) toward the Caudatum race and its intermediate forms.

Racial distribution was markedly different among regions. Sorghums from Gezira-Gedarif included 14 races made up mainly of Caudatum and its intermediate races. Among landraces from the Kassala region, six races were present with Caudatum and Durra equally represented. Race Bicolor represented as high as 16% of the landraces from Kassala. This is much higher than the frequency of the Bicolor sorghums in the total Sudanese collection (4%). In the Blue Nile region, six races of sorghum were included with race Caudatum as the most dominant (49%) followed by its intermediate Caudatum-Guinea (27%). More races were included in landrace sorghums from Upper Nile where there too, 70% of the landraces were classified as Caudatum. The less diverse region, race-wise, was Equatoria, where only 10 Caudatum, 4 Guinea, and 4 Caudatum-Guinea landraces were reported.

Descriptive statistics were performed on the total collection as well as for group of accessions based on area of origin. Geographic partitioning of phenotypic diversity in each of these regions was tested through variance analysis. To avoid redundancy and improve readability, the results of these analyses were presented by grouping related traits together under the general categories of quantitative and qualitative characteristics.

Phenotypic diversity among landraces was high, as expressed by the large range of variation for mean quantitative traits and the high Shannon-Weaver Diversity Index (0.80). Landraces from Gezira-Gedarif tended to be shorter in stature, earlier in maturity and less sensitive to changes in photoperiod. They also appeared to have long, narrow and compact panicles that may result from adaptation to low rainfall and early adoption of mechanized farming practices. In contrast, taller and later maturing plant types characterized sorghums from Equatoria, most of which delayed their flowering in response to increased day-length. These sorghums included many genotypes with small and light kernels, suggesting possible utilization as fodder. Furthermore, sorghums from Equatoria along with those from the Upper Nile tended to have loose panicles with poorly covered kernels that may result from adaptation to high rainfall of the Southern region. Collections from Kassala showed a higher frequency of landraces with yellow midribs, well covered, and colored kernels that were more difficult to thresh. Landraces from Blue Nile tended to have greater agronomic eliteness with mainly compact panicles, white kernels, no subcoat, and easy to thresh. Although distinct distributions of types were represented by geographical origin, a high level of within-region diversity was present among all Sudanese sorghums.

Phenotypic diversity was estimated by using multivariate analyses of several morphological characters. A principal component analysis involving all 10 quantitative characters was performed where factors were retained when their given value exceeded the value of one. The first three axes explained 62% of the observed phenotypic diversity among landraces from the Sudan . The first axis accounted for 33% of the variance and was significantly and positively associated with plant height and days to flowering recorded during both the rainy and post-rainy seasons. The second axis explained 17% of the variance and was associated with kernel size and 100-seed weight. A third axis, explaining 11% of the variance was associated with panicle length. Plotting the accessions on the first two axes as well as on the first and third factors (not shown) graphically demonstrated that landraces from different regions cover the factorial space unequally. For instance, sorghums from Gezira-Gedarif, despite covering the greatest space, were more densely represented on the factorial space corresponding only to the shortest and earliest plants. On the other hand, accessions from Upper Nile that are largely and evenly distributed on the first axis, had more landraces represented in the factorial space where large and heavy seeded sorghums were plotted. Sorghums from Blue Nile were mainly represented by small and light seeded landraces. The tallest and latest flowering plants of accessions from Blue Nile had the largest and heaviest seeds. Similar observation could be made for sorghums from Kassala, although the distribution in the factorial space was more compact in this group. Landraces from Equatoria, however, were neatly plotted away from landraces from other regions. It was apparent that Equatoria sorghums were small-seeded, tall in stature and among the latest flowering in maturity.

Diversity was also estimated using the Shannon-Weaver diversity index calculated from frequency distribution of multiple morphological traits. Estimates were based on phenotypic variability of the landraces, only considering the qualitative characters. High global index of diversity (H'=0.80) was found in the total collection. Within region, however, the range of index of diversity varied from H'=0.60 for accessions from Equatoria, to H'=0.79 for sorghums from Gezira-Gedarif. Pair-wise comparison of the indices using the *t*-test revealed significant differences (at $p<0.05$ probability-level) between the diversity indices obtained from Blue Nile (H'=0.67) and the total collection (H'=0.80) as well as between Blue Nile and Gezira-Gedarif (H'=0.79).

Networking Activities

Workshop and Program Reviews

Participated in the evaluation of a Food Security Project for the Amhara Region in Ethiopia at the invitation of USAID/Ethiopia, May 5-12, 2001, Addis Ababa, Ethiopia.

Participated in a study on survey of available technologies for use in development of drought tolerant crops in Eastern Africa for the Inter-Governmental Agency for Development, May 12-18, 2001, Nairobi, Kenya.

Attended and chaired two sessions at the 7th International Parasitic Weed Conference, 6-8 June, 2001, Nantes, France.

Attended International Conference on Contemporary Development Issues in Ethiopia, 16-18 August 2001.

Organized a stakeholders conference to discuss findings of regional study on state of technologies for drought tolerant crops in East Africa, 27-31 October 2001, Nairobi, Kenya.

Traveled to Ethiopia to initiate a program on community-based improved sorghum seed multiplication and integrated *Striga* management program for Ethiopia and Eritrea, 10-22 December, 2001.

Research Investigator Exchange

Visited University of Paris and the Tropical Agricultural Research Centre (CIRAD) and held discussions with staff at both institutions regarding collaborative research on sorghum *Striga* resistance, 10-12 June 2001, France.

Hosted international visitors from Ethiopia, Tanzania, Zimbabwe, and Australia.

Germplasm Exchange

We continue to provide an array of sorghum germplasm from our breeding program to national research programs in developing countries. Our germplasm is provided in either a formally organized nursery that is uniformly distributed to all collaborators that show interest or upon request by a national program of specific germplasm entries or groups from or germplasm pool. Germplasm was distributed to cooperators in 25 countries in 1996, 15 countries in 1997, 10 countries in 1998, and 7 countries in 1999.

Three new *Striga* resistant varieties of sorghum from our program in 2001 were recommend for commercial cultivation in two African countries, one in Tanzania and two in Ethiopia.

Publications

Refereed Papers

Mohammed, A., G. Ejeta, and T. Housley. 2000. *Striga* asiatica seed conditioning and 1-aminoacylopropane-1- carboxylate oxidase activity. Weed Research 41:165-176.

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Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-222

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Summary

The principal objectives of TAM-222 are to identify and develop disease resistant and drought resistant sorghum germplasm in genetically diverse backgrounds for use by host country and U.S. scientists, to identify, evaluate, and utilize new elite exotic germplasm, and to collaborate with host country scientists in all aspects of their crop improvement programs. The disease and drought resistance breeding program continued to develop and evaluate new germplasm for use in the U.S. and host countries. Four A/B female parental lines, A/BTx642 - Tx645, previously known as A/B35, 1, 803, and 807, were released. They possess drought resistance (pre and post-flowering and lodging resistance). Forty-eight new fully converted exotic lines and 70 partially converted lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were identified for release.

Data and characterization on the Mali Sorghum collection of indigenous sorghum cultivars was completed and entered into the USDA-ARS GRIN system. Several very unique and promising new Durra and Durra-Dochna type cultivars from the dry northern part of Mali were identified in the Collection, and hold promise in sorghum improvement in the drought prone areas of Africa and the U.S. Twenty-five sorghums from the Mali Collection were selected for entry into the Sorghum Conversion Program.

Breeding progeny developed in TAM-222 showed excellent potential in the Zambia, South Africa, Nicaragua, El Salvador, and in South and West Texas with various combinations of high yield, drought resistance, grain quality, and disease resistance. They offer good potential for use as varieties directly where appropriate and also as parental lines for use in hybrids. Macia (an improved cultivar from Mozam-

bique) derivative lines looked especially promising and also offer potential to develop some improved white-seeded, tan-plant parental lines for U.S. use.

Sterilization and evaluation continued on a large number of new B-line breeding genotypes to assist decisions on which ones to release. These lines contain various combinations of stay green drought resistance, lodging resistance, improved grain quality, and head smut resistance. Several are white-seeded, tan-plant A-B pairs that could be useful in food-type hybrids.

Flour made from the IER/INTSORMIL developed tan plant guinea cultivar, N'Tenimissa, was successfully used in Mali by a private bakery (GAM) to produce and market a new cookie, DeliKen, made with 20% sorghum flour being substituted for wheat flour. A private entrepreneur was successful in organizing the production of 13,800 kg of N'Tenimissa in 2001 and had initiated new markets in addition to the GAM bakery. This demonstrates that new cultivars with improved grain quality traits can stimulate the development and commercialization of new sorghum-based products. Some of the new N'Tenimissa breeding progenies show good promise to be even superior to N'Tenimissa for production and grain quality. One of the new cultivars, 97-SB-F5DT-63, N'Tenimissa* Tiemarfing, has been released and called Wasa.

Collaborative INTSORMIL activities were initiated in Senegal and Ghana in the areas of sorghum breeding, disease resistance, and Striga, as well as in entomology and agronomy research. MOU's are currently in place with both countries.

Objectives, Production and Utilization Constraints

Objectives

U.S.

- Develop and release agronomically improved disease and drought resistant lines and germplasm and identify new genetic sources of desirable traits. Select for drought resistance with molecular markers. Evaluate new germplasm and introgress useful traits into useable lines or germplasm.

Western Region/West Africa (Mali, Ghana, Senegal)

- Develop, release, and distribute agronomically acceptable white-seeded, tan-plant Guinea type sorghum cultivars to enhance the commercial value and demand for improved value, high quality sorghum grain.

- Develop high yielding white, tan non-Guinea type improved cultivars with high levels of resistance to head bug and grain mold with adaptation to the drought and soil conditions of West Africa, and with acceptable levels of disease resistance. Characterize and describe the indigenous Mali origin Sorghum Collection and evaluate for useful traits and breeding potential, introduce into U.S., and place in storage in U.S., ICRISAT, and ORSTOM.

- Initiate collaboration with scientists in Ghana and Senegal including breeding, pathology, entomology, agronomy, and *Striga* research.

Central America

- Enhance germplasm base with sources of resistance to grain mold, foliar diseases and drought, and food type sorghums, and lines for adapted commercial hybrids.

Horn of Africa and Southern Africa

- Enhance drought resistance, disease resistance, and germplasm base with the development of improved high yielding, adapted germplasm and elite lines.

Constraints

Drought is the major constraint to sorghum and millet production around the world. West Texas has a semi-arid environment ideal for large scale field screening for both pre- and post-flowering drought response and breeding for improved resistance to drought.

Diseases are important worldwide and most internationally important diseases are present and are also serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. The Texas environment, particularly South Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

Poor grain quality is a major problem over much of West Africa and is primarily due to the head bug/grain mold complex. Head bugs are a major constraint to the use of improved high yielding nonguineense type sorghums in much of West Africa, with head bug damage often compounded by grain mold, resulting in a soft, discolored endosperm, which is unfit for decortication and traditional food products. Early maturity of introduced types also increases the grain deterioration problem. In the southern regions, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season.

Much of West Africa, especially the more northern areas, are drought prone areas where drought tolerance is important. Foliar diseases such as anthracnose and sooty stripe are important in the central and southern parts and in certain areas of Southern Africa along with leaf blight. In much of East Africa, the major constraint is drought, and related production problems. Moisture-stress related charcoal rot and subsequent lodging are serious problems. *Striga* is a major constraint in most areas including Mali, Niger, and Sudan.

In Central America, diseases and grain quality are major constraints, with drought also important in the drier portions of the region. Improvement in the photoperiod sensitive, food-type maicillos criollos grown in association with maize on small, hillside farms is a unique challenge.

There is a constant need in both host countries and the U.S. to conserve genetic diversity and utilize new diverse germplasm sources with resistance to pests, diseases, and environmental stress. Many developing countries are an important source of diverse germplasm in sorghum and millet. The collection, preservation and utilization of genetic diversity in sorghum is important to long-term, sustainable sorghum improvement programs needed to insure sufficient food for increasing populations of the future.

Research Approach and Project Output

Research Methods

Introductions from various countries with drought or disease resistance, or specific desirable grain or plant traits, are crossed in Texas to appropriate elite U.S. lines or elite breeding materials. Seed of the early generations are sent to host countries for selection of appropriate traits and adaptation. Technical assistance is provided, as time and travel permits, in the selection and evaluation and use of such breeding material in the host country.

Disease resistant breeding material is generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance. Initial screening is primarily in large disease screening nurseries utilizing natural infection in South Texas. Selected advanced materials are sent to host countries as appropriate for evaluation and are also incorporated into various standard replicated trials for extensive evaluation at several locations in Texas and host countries.

Breeding crosses involving sources of drought resistance are selected under field conditions for pre- and/or post flowering drought resistance, yield, and adaptation at several locations in West Texas. Molecular markers for the stay green trait are being used in a marker assisted selection program. Selected advanced materials are incorporated into standard replicated trials for evaluation at several locations in Texas and sent to host countries for evaluation and use.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials are screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm is assembled or collected as opportunities exist and introduced into the U.S. through the quarantine greenhouse (small number of items) or the USDA Plant Quarantine Station in St. Croix (many items), they are then evaluated in Puerto Rico and Texas for useful traits. Selected photoperiod sensitive cultivars are entered into the cooperative TAES-USDA Sorghum Conversion Program. Cooperative work with NARS assures their country's indigenous sorghum cultivars are preserved in long term permanent storage in the U.S. at the NSSL, as well as evaluated and used in germplasm enhancement programs. Growouts of entire collections (Sudan and Mali) have been grown in their country of origin for characterization, seed increase and evaluation prior to introduction into the U.S. Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs.

Research Findings

Breeding, selection, and screening for drought resistance continued, using major field screening nurseries at Lubbock, Halfway, Chillicothe, Corpus Christi and Beeville. Extreme stress at Chillicothe and Lubbock resulted in severe pre-flowering stress and the loss of most of the Lubbock dryland plots. The "stay green" line, B35, continues to be an excellent source of post-flowering drought resistance and lodging resistance in breeding progeny. Breeding derivatives of the parental line, B1, a derivative of B35, showed some good drought resistance, with many showing outstanding lodging resistance especially the pedigrees (B1*(B7904*(SC748*SC630))), (B1*BTx635), and (B2-1*BTx635). Sterilization and hybrid evaluation continued on the above mentioned B lines which includes several white seeded, tan plant lines.

New disease resistant breeding materials were developed, screened, and selected along with advanced generation breeding materials for improved agronomic types with high levels of, and/or multiple, disease resistance. Screening and selection was done primarily in large disease screening nurseries, mostly in South Texas. Major diseases involved were downy mildew, head smut, anthracnose, grain mold/weathering, and charcoal rot. Resistance to other foliage diseases such as rust, zonate, and gray leaf spot was also selected in some nurseries.

Four advanced generation female parental A/B lines known as A/B35, A/B1, A/B803, and A/B807 were officially released by the Texas Agricultural Experiment Station in June 2002. These lines were released as A/B Tx642, Tx643, Tx644, and Tx645, respectively. ATx642 and 643 possess good post-flowering drought tolerance (stay green) and good lodging resistance (Table 1). The hybrids of ATx642 (A35) are outstanding in their stay green reaction and have excellent charcoal rot resistance and stress-type lodging resistance. Hybrids with ATx643 are not as stay green, depending on the male parent, but usually have quite good pre-flowering drought tolerance. Hybrids with ATx644 and ATx645 show good pre-flowering drought tolerance, and ATx645 hybrids possess an improved level of grain weathering resistance.

Table 1. Agronomic characteristics and disease ratings of BTx642-BTx645 sorghum parental lines and hybrids in various sites throughout Texas.

Location/Destination		Days to anthesis	Plant height in	Panicle exertion in	Agronomic* desirability rating	LPD*** rating	Stalk lodging %	Grain weight gms/1000
							%	
Lubbock	BTx642	71	38	5	2.2	1.4	0	28.4
	BTx643	65	36	1	2.0	1.7	5	30.1
	BTx644	58	35	4	2.5	1.5	7	23.8
	BTx645	62	40	3	2.2	2.2	13	30.4
	BTx378	70	37	3	2.8	2.7	20	31.4
	BTx623	64	40	2	2.6	2.8	50	30.6
Corpus Christi	BTx642	80	38	6	2.9	2.6	0	-
	BTx643	78	38	2	1.9	2.6	0	-
	BTx644	78	36	5	1.9	2.7	2	-
	BTx645	77	38	4	2.1	3.3	10	-
	BTx378	75	39	5	2.4	3.2	15	-
	BTx623	78	42	3	2.1	3.5	20	-

*1 = very good to 5 = very poor; ** = Leaf and plant death rating: 1 = all green, 3 = 50% of leaf area dead, 5 = entire plant dead;
BTx642 = B35; BTx643 = B1; BTx644 = B803; BTx645 = B807

Designation	Head Smut (%)	Downy mildew (%)	Anthracnose rating	Fusarium head blight rating	Chemical Insecticide burn rating	Pre-flowering drought rating	Post-flowering drought rating
BTx642	0	10	4.8	1.0	3.5	4.0	2.6
BTx643	30	0	4.0	1.0	1.0	2.5	2.6
BTx644	5	0	3.0	2.5	1.0	3.1	2.7
BTx645	10	0	4.0	3.0	1.0	2.1	3.3
BTx378	3	2	1.0	3.5	3.0	2.7	3.4
BTx623	30	0	5.0	2.5	1.0	3.3	3.5

All ratings were taken at Corpus Christi except Anthracnose (College Station) and Fusarium head blight (Lubbock).
Disease and burn ratings 1 = resistant through 5 = death.
Drought rating 1 = very good through 5 = very poor.

Hybrid/Pedigree	LPD[1] rating	LPD[1] rating	Lodging[2] percent (%)
	1993	1994	1994
ATx642*Tx430	2.6	2.7	2
ATx643*Tx430	3.8	3.9	31
ATx642*Tx436	2.6	2.7	1
ATx643*Tx436	3.5	4.1	7
ATx642*BE2668	2.6	2.7	4
ATx643*BE2668	3.3	4.0	22
ATx644*BE2668	-	3.1	6
ATx645*BE2668	-	4.1	26
ATx642*86EON361	2.9	2.9	3
ATx643*86EON361	4.0	4.5	68
ATx642*P37-3	3.2	2.5	3
ATx643*P37-3	4.3	4.7	62
ATx642*89CC443	-	-	-
ATx399*Tx430 (check)	-	4.2	41
ATx2752*Tx430 (check)	-	4.0	27
ATx378*Tx430 (check)	-	4.3	55
DK 46 (check)	-	3.2	8

[1]Leaf and plant death rating: 1 = all green; 3 = 50% of leaf area dead; 5 = entire plant dead. Ratings are mean of Lubbock and Halfway.
[2]Primarily moisture stress type lodging, Lubbock

Approximately 30 A-B pairs and 8 R lines developed cooperatively with L.E. Clark in the cooperative drought breeding program have been identified for possible release. These lines contain many traits with emphasis on stay green, and lodging resistance. Several are white-seeded tan plant lines and some show enhanced weathering resistance. These will be proposed for release mostly as germplasm stocks. Another set of advanced generation germplasm releases containing various desirable traits, including resistance to downy mildew, head smut, grain mold/weathering, anthracnose, charcoal rot, both pre- and post-flowering drought resistance, food type grain quality, and lodging resistance was tentatively identified.

Forty-eight new fully converted lines are now ready for final release preparation and distribution. Data was obtained on a set of 27 and the other set of 21 was selected from seed increase and purification plots. These are cooperative TAMU-TAES/USDA-ARS releases from the sorghum conversion program. In addition, 71 partially converted bulks are ready for release writeup and distribution.

Molecular analysis using RFLP markers, collection of field drought data, and manuscript preparation continued on 100 F_8 recombinant inbred lines (RILs) each of (B35*Tx430) and (B35*Tx7000). Of the five QTL's identified for the stay green trait in the cross (B35*Tx7000) two (Sg2 and Sg3) appearing to be the most important. In the cross (B35*Tx430), the same QTL's were identified for stay green along with two others, and five QTL's were identified for yield. Two hundred progenies each from two other populations, B35*Tx7000 and SC56*Tx7000, were also evaluated for drought and lodging. Several QTLs were identified for pre- and post-flowering drought resistance and lodging resistance. Two of the QTLs for stay green in the SC56 population were the same as those previously identified from B35. All the above research was in cooperation with Henry Nguyen of Texas Tech/TAES. Near isogenic lines (NILs) were developed (BC6) to do fine mapping of stay green QTLs and to do functional genomics and stress physiology research in cooperation with scientists in Australia. In another project, advanced backcross populations and hybrids were generated and evaluated to identify QTLs for yield and heterosis in exotic germplasm.

Several new tan-plant N'Tenimissa derivative guinea type breeding lines looked promising in Mali in 2001, showing less stalk breakage, and better head bug resistance than N'Tenimissa. One line, 97-SB-F5DT-63, N'Tenimissa* Tiemarfing, has been released and is called Uassa. Also, some new, shorter N'Tenimissa derivative F_4 and F_5 lines showed real promise. Selection also continued among non-guinea type, tan-plant breeding lines with improved levels of head bug tolerance and grain mold resistance. A local private entrepreneur successfully organized the production of a large quantity of grain of N'Tenimissa in 2001 in the Bamako area and has initiated new market for the flour.

DeliKen, a locally produced cookie, made partially using flour from the recently developed tan plant Guinea-type sorghum variety, N'Tenimissa, was marketed successfully in the Bamako, Mali area by GAM, the largest local bakery of bread and cookies in Bamako. It was favorably received and was strongly promoted by the Mali government.

From the evaluation of lines and hybrids in Nicaragua, several Texas A&M developed materials look excellent and seed was requested for evaluation again in 2002 (Table 2).

Table 2. Sorghum cultivars and hybrids with the best agronomic potential selected from 2001 nurseries in Nicaragua for further evaluation in 2002. All are white seeded, tan plant unless indicated.

Designation/Pedigree/Source	
(Cultivars)	
96CD635/(SRN39*90EON328)-HF4	
98CD187/(87EON366*90EON328)-HF6	
99GWO92/86EON361*90EON343)-HD12	Red, Tan
(SRN39*90EON328)-HF4..CA2/OOCA4295	
(Macia*Dorado)-HP4..CA2/OOCA4834	
(Macia*Dorado)-HD12/OOCA4846,7	
(Macia*Dorado)-LL2/OOCA5129,34	
(Macia*Dorado)-LL6/OOCA5146,7	
(Macia*Dorado)-LL7/OOCA5159	
(Macia*Dorado)-HD12/OOCA4842,3,5	
(ICSV1089BF*Macia)-HF9/OOCA5189,93	
(ICSV1089BF*Macia)-HF11/OOCA5194,5	
ICSV1089VF*Macia)-HF2/OOCA5169	
(Hybrids)	
ATx631*86EON361	
A.HF14*86EON361	
A.HF8*86EON361	
A.V26*86EON361	
A.V57*86EON361	
A.LD6non*86EON361	
A.HF4(3d)*86EON361	
A.DLO357*86EON361	Red, Purple
ATx631*Tx436	
A.LD6non*Tx436	
A.V57*Tx436	
A.HF4(3d)*91BE7414	
A.HF14*R.9113	Red, Tan
A.HF14*CA4205	Red, Tan
A.LD6non*BRON299(EO361*Macia)	
A.LD6non*GR134/GCPOB124	Red, Tan
A.LD6wxy*GR134/GCPOB124	Red, Tan
A.DLO357*Tx2783	Red, Purple
A.DLO357*88BE2668	Red, Purple

Several breeding progeny from crosses generated for Host Country use, as well as U.S. use, looked very good in several locations, especially in Zambia and South Africa. Some show excellent yield potential as well as good disease resistance. Some progenies also show good drought resistance combined with yield potential. Many Macia and Dorado derivatives looked excellent. Other lines giving good progeny included 86EON361, 87EON366, 90EON328, Sureno, SRN39, TAM428, ICSV1089BF, WSV387, CE151, and MP531.

Leaf blight and ergot were especially severe in Cedara, South Africa in the 2001-2002 season on the ADIN and SABN with excellent ratings obtained (Tables 3 and 4). Agronomic expression was excellent under rather dry conditions at Golden Valley, Zambia and selected progenies with the best ratings are presented in Table 4.

In southern Zambia at Lusitu under extremely severe drought, the lines given below from the Drought Line Test showed excellent drought resistance and produced meaningful quantities of grain, when most other sorghum entries and farmer production was zero. Lines from the DLT with excellent drought resistance included Tx7078, Tx7000, Ajabsido, El Mota, P954035, SC1154-14E, SC1017-14E, SC701-14E, SC265-14E, CE151-262-A1, Macia, Kuyuma, CSM63, 82BDM499, and 88V1080.

Networking Activities

Workshops/Conferences

Participated in the Central America INTSORMIL Research Reporting and Planning Conference, February 26 - March 1, 2002, Managua, Nicaragua.

Participated in and presented plans for new release at the Texas Seed Trade Association (TSTA) Research Conference, February 4-5, 2001, Dallas, Texas.

Participated in the Annual ASTA (American Seed Trade Association) Sorghum and Corn Research Conference, December 5-7, 2001, Chicago, Illinois.

Table 3. Disease and agronomic performance of selected ADIN entries, Cedara, South Africa, 2001-02.

Designation	Desirability[1/] rating	Leaf[2/] blight	Ergot[3/] rating
R9120	2.5	1.0	15.0
SC414-12E	3.0	1.3	38.5
Tx430	3.5	1.0	36.0
Tx2911	3.2	1.8	34.0
BTx631	2.3	0.8	19.0
BTx635	3.0	0.5	26.5
BTx623	2.8	4.0	22.0
SRN39	2.6	3.0	9.5
Tx2783	3.0	2.8	21.5
Tegemao	2.2	3.0	3.5
B35	2.8	0.8	10.0
Tx7078	3.3	2.0	19.5
Tx436	2.2	0.2	11.0
Malisor 84-7	2.0	0.5	18.5
Sureno	2.2	0.3	24.5
SC630-11E	2.5	0.0	29.5
BTx378	3.5	0.5	10.0
SC326-6	3.4	0.0	38.5
86EON361	2.0	0.0	19.0
91BE7414	1.5	0.0	8.0
90EON328	2.0	1.5	6.5
R9618	2.0	0.5	20.0
88BE2668	2.2	1.5	5.5
R9603	1.2	0.5	4.5
MB108B	2.0	3.0	9.0
CA5986	2.0	1.0	7.5
BRON155	2.2	0.3	16.5
BD1982-4	2.2	3.8	9.0
98CD187	1.5	2.8	7.5
96CD635	3.0	1.8	11.5
GCPOBS160	2.0	0.3	13.5
R9519	2.0	0.5	9.0

[1/] Rating 1 = very good to 5 = very poor. By D.T. Rosenow.
[2/] Rating where 0 = completely resistant to 5 = severe disease. By N. McLaren.
[3/] Rating done as mean percentage infected florets. By N. McLaren.

Table 4. Disease and agronomic ratings on selected SABN (Southern Africa Breeding Nursery) entries, Golden Valley, Zambia, and Cedara, South Africa, 2001-2002.

Designation/Pedigree	Desirability[1/] rating G. Valley	Desirability[1/] rating Cedara	Leaf[2/] blight Cedara	Ergot[3/] rating Cedara
(CE151*MP531)-LD12	1.2	1.5	1.3	0
ZSV15	1.5	2.8	2.2	0
ICSV1089BF	1.5	2.2	2.2	7.5
(87EON366*WSV387)-HD27	1.5	2.8	2.5	0
(87EON366*WSV387)-HF14	1.5	2.0	2.0	0
(M84-7*WSV387)-HD7	1.5	3.0	1.5	9.0
(Macia*Dorado)-HD12—CA1	1.5	3.0	2.0	2.5
(Macia*Dorado)-LL1-CA1	1.5	2.9	1.5	0
(Macia*Sureno)-HF19	1.5	3.0	0.8	2.5
(90EO328*CE151)-LD11	1.5	1.8	0.8	2.5
96CA5986 (Sureno*EO366)	1.8	2.5	1.0	9.0
98CA4598(361*343)-HD12	1.8	3.2	3.0	14.5
(SRN39*EO366)-LD39	1.8	2.4	3.3	9.5
(EO366*WSV387)-HD27	1.8	2.7	2.8	5.0
(Macia*Dorado)-HD12—CA3	1.8	2.8	1.5	0.0
(Macia*Dorado)-HD2—CA1	1.8	3.2	2.0	0.0
(Macia*Dorado)-LL2	1.8	3.0	3.0	1.0
(Macia*Dorado)-LL5	1.8	2.5	1.0	9.5
(Macia*Dorado)-LL7	1.8	2.5	1.3	1.0
(ICSV1087BF*Macia)	1.8	3.2	1.0	11.0
Sureno	2.0	3.0	2.0	4.0
86EON361	2.0	2.0	1.0	8.5
Macia	2.0	2.5	2.0	0.0
Kuyuma	2.0	3.0	2.0	0.0
Tegemao	2.0	2.8	2.8	2.5
90EON328	2.0	3.0	2.4	0.0
B.PDLT157	2.0	3.0	4.3	6.0
96CD635	2.0	3.0	2.3	2.5
(EO366*EO328)-HF9	2.0	2.2	2.8	2.5
(Sureno*SRN39)-LD2	2.0	3.2	2.8	23.0
(EO366*WSV387)-HF24	2.0	2.0	0.8	25.0
(EO361*Macia)-HD15	2.0	2.3	0.5	10.0
(EO361*Macia)-HD19	2.0	3.2	2.0	3.5
(Macia*Dorado)-LL1-CA3	2.0	3.2	1.5	0.0
(Macia*Dorado)-LL6	2.0	3.2	2.0	3.5
(Macia*TAM428)-LL14	2.0	2.0	1.5	1.0
(ICSV1089BF*Macia)-HF2(BE1)	2.0	1.5	1.3	3.5
(CE151*MP531)-LD47	2.0	2.2	1.0	0.0
(Sepon82*EO366)-HF38	2.0	2.0	1.5	2.5
(Macia*TAM428)-LL3	2.2	2.5	1.0	1.5
Sima/WSV187	2.5	3.0	1.0	1.1
82BDM499	2.5	2.2	2.2	2.0
TAM428	2.5	3.0	3.8	1.5
Dorado	2.5	3.4	2.3	4.0
98CD187-2	2.5	2.5	0.5	0.0
R2241 der.	2.5	2.3	0.3	5.0
87EON366	2.8	2.6	2.8	22.0
CE151-262-A1	2.8	2.2	2.2	1.0
SRN39	2.8	3.2	3.0	6.5
91BE7414	2.8	2.0	0.0	5.0
(Sureno*EO362)-HF9	2.8	2.0	0.8	0.0
(EO366*TAM428)-HF15	2.8	2.0	2.0	3.0
(ICSV1089BF*Macia)-HF11	2.8	2.0	0.8	2.5
(87EO366*WSV387)-HF3	—	2.0	1.8	2.5
90EL328 der.	—	2.0	2.0	5.0
(CE151*Macia)-BE22	—	2.0	0.8	5.0

[1/] Rating 1 = very good to 5 = very poor. By D.T. Rosenow.
[2/] Rating where 0 = completely resistant to 5 = severe disease. By N. McLaren.
[3/] Rating done as mean percentage infected florets. By N. McLaren.

Serving on Planning committee for the INTSORMIL P.I. Conference in Ethiopia, November 2002.

Research Investigator Exchanges

Traveled to Managua, Nicaragua Feb. 25 - March 1, 2002 to review and plan collaborative INTSORMIL research in Central America with scientists from Nicaragua, El Salvador, and the U.S.

Traveled to Southern Africa region March 31 - April 15, 2002 to evaluate INTSORMIL collaborative sorghum research and plan future activities with scientists from Botswana, Zambia, Zimbabwe, and South Africa; Botswana - April 2-4, Dr. Peter Setimela, sorghum breeder, and others; Zambia - April 4-7, Dr. Medson Chisi, sorghum breeder, and Leo Mpofu, sorghum breeder from Zimbabwe; South Africa - Dr. Neal McLaren, pathologist, Dr. Johnie van den Berg, entomologist, and Prof. John Taylor, Cereal Scientist.

Hosted Dr. Janos Berenji, Sorghum Breeder from Yugoslavia and viewed sorghum research and discussed sorghum breeding and germplasm at Corpus Christ, TX, July 27-28, 2001.

Visited with Rafael Obando, Rene Clara, and Hector Deras at Corpus Christi July 30 and 31, 2001 and evaluated sorghum breeding nurseries and tests.

Arranged travel and hosted Dr. Ibrahim Atokple, Ghana Sorghum Breeder at Lubbock August 13 - September 29, 2001 for breeding training and evaluation of diverse germplasm and advanced breeding material.

Arranged the travel of Mr. Kissima Traore, Sorghum Breeding Technician from Cinzana, Mali for short-term breeding training at Lubbock, TX, September 2 - October 6, 2001.

Visited with Dr. Grame Hammer, Sorghum agronomist and sorghum plant stress modeling expert from Queensland, Australia, November 14, 2001 at Lubbock, TX.

Visited with Dr. Peter Esele, Pathologist from Uganda, November 29-30, 2001, Lubbock, TX, and discussed INTSORMIL research in Uganda and the Horn of Africa Region.

Hosted Dr. Andrew Borrell, Sorghum Stress Physiologist, and Dr. David Jordon, Sorghum Breeder, Queensland, Australia, at Lubbock, TX January 17-29, 2002 and discussed future collaborative physiology and molecular collaborative research on stay green, a post-flowering drought resistant trait in a cooperative research program involving Texas A&M, Texas Tech, and Queensland.

Interacted with INTSORMIL and Host Country scientists at the TC Meetings, November 29-30, 2001 at Kansas City and at the Host Country Coordinators Meeting, P.I. Conference Planning Committee Meeting, and TC meeting April 29-May 3, Lincoln, NE.

Coordinated the training of Mr. Niaba Teme, former sorghum technician with IER, Mali who is nearing completion of his M.S. degree at Texas Tech University, cooperative with TAES at Lubbock.

Interacted with several private seed company scientists at various times, such as at the TSTA Research Conference, ASTA Corn and Sorghum Research Conference, and at the Sorghum Advisory Committee Growouts at Tampico, Mexico, Feb. 20-22, 2002, as well as in individual scientist visits to the TAES research station at Lubbock.

Hosted Dr. Ed Clark, retied TAES Sorghum Breeder and Agronomist, December 13-14, 2001, to evaluate potential releases and develop plans for release of several sorghum drought and lodging resistant sorghum lines developed cooperatively with Dr. Clark.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Continued the coordination of the work with the Mali Sorghum Collection with the completion of the data and characterization and entry into the USDA/ARS GRIN system. The mid-maturity group of about 1000 items was grown there the winter of 2000-2001. The Collection was evaluated, characterization completed, and a tentative working collection identified in cooperation with Drs. Aboubacar Toure, Jeff Dahlberg, and John Erpelding, and Mr. Niaba Teme. After the seed was sent to Experiment, Georgia and has been processed, seed of the entire collection will be sent to NSSL at Ft. Collins, Colorado and will be distributed as appropriate to ICRISAT, ORSTOM, and IER. The complete set of data on the over 40 grain, glume, and plant characterizations was complied by Jeff Dahlberg and sent to the USDA-ARS for entry into the GRIN system.

Nineteen new sorghum breeding lines from IER, Mali were introduced into the U.S. These included some Durras from northern Mali and white-seeded, tan-plant, good food quality guinea derivative and non-guinea types. The 35 lines introduced from Mali in 1999 were evaluated (all were photoperiod sensitive) and were increased in '00-'01 Puerto Rico and evaluated for B/R fertility restorer reaction.

Two sets of new fully converted exotic lines (27 and 21 items) from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were selected for release and are being prepared for release along with 70 partially converted lines.

Seed Production and Distribution

A large number of sorghum breeding and germplasm lines, from early to advanced generation progeny, A, B, and R lines, converted lines, and experimental hybrids were increased and distributed to international and domestic collaborators. These contained sources of desirable traits such as resistance to downy mildew, anthracnose, sooty stripe, leaf blight, rust, and charcoal rot, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance. Seed was increased and many sets of standard replicated trials containing elite germplasm and source lines were packaged and distributed in the U.S. and internationally. These include the ADIN (All Disease and Insect Nursery), GWT (Grain Weathering Test), DLT (Drought Line Test), DHT (Drought Hybrid Test), and the UHSN (Uniform Head Smut Nursery). Also, special drought trials and elite germplasm nurseries were assembled and distributed. Countries to which large numbers of germplasm items were distributed include Mali, Niger, Ghana, Senegal, Nigeria, Burkina Faso, Zimbabwe, Botswana, Zambia, South Africa, Ethiopia, Guatemala, El Salvador, Nicaragua, and Mexico.

Assistance Given

Joint evaluation of germplasm and nursery and test entry decisions was done collaboratively with national scientists. Training on disease and drought breeding methodology, as well as information on sources of new useful germplasm and sources of desirable traits, was provided to several visitors. Pollinating bags, coin envelopes, and other breeding supplies were provided to the Mali breeding program. Purchases included computers for Ghana and Mali, a fax machine for Mali, and other miscellaneous supplies for Mali.

Other Collaborators

Cooperation or collaboration with the following scientists in addition to the collaborating scientists previously listed was important to the activities and achievements of Project TAM-222.

Dr. Issoufou Kapran, Sorghum Breeder, INRAN, Niamey, Niger.

Dr. Aberra Debelo, Ethiopian Country Cooridnator, EARO, Addis Ababa, Ethiopia.

Dr. Fred Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali

Dr. Eva Weltzien Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali.

Dr. Inoussa Akintayo, WCASRN Coordinator, WCASRN, ICRISAT, Bamako, Mali.

Dr. Peter Setimela, Sorghum Breeder, University of Botswana, Gabarone, Botswana.

Mr. Leo Mpofu, Sorghum Breeder, Plant Breeding Institute, c/o SADC/ICRISAT , Bulawayo, Zimbabwe.

Dr. John Erpelding, Sorghum Curator, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Dr. Mitch Tuinstra, Sorghum Breeder, Kansas State University, Manhattan, KS 66506.

Dr. Ken Kofoid, Sorghum Breeder, Ft. Hays Branch Station, KSU, Hays, KS.

Dr. Jeff Dahlberg, Research Director, National Grain Sorghum Producers Association, Lubbock, TX.

Dr. Andrew Borrell, Physiologist, QDPI, Warwick, QLD, Australia.

Publications and Presentations

Journal Articles

H. Kebede, P.K. Subudhi, D.T. Rosenow, and H.T. Nguyen. 2001. Quantitative trait loci: influencing drought tolerance in grain sorghum (*Sorghum bicolor* L. Moench). Theor Appl. Genet. 103:266-276.

Sanchez, A.C., P.K. Subudhi, D.T. Rosenow, and H.T. Nguyen. 2002. Mapping QTLs associated with drought resistance in sorghum (*Sorghum bicolor* L. Moench). Plant Molecular Biology 48:713-726.

Books, Book Chapters, and Proceedings

Subudhi, P.K., H.T. Nguyen, M.L. Gilbert, and D.T. Rosenow. 2002. Sorghum Improvement: Past Achievements and Future Prospects. In Manjit S. Kang (Ed.) Crop Breeding: Challenges in the Twenty-First Century. Food Products Press. Pp.109-159.

Abstracts

Rodriguez-Ballesteros, O.R., A.S.B. Mansuetus, R.D. Waniska, R.A. Frederiksen, G.N. Odvody, and D.T. Rosenow. 2000. Free and bound phenolic acids in mature sorghum caryopses as affected by inoculation with Fusarium thapsinum. In Proc. of Global 2000: Sorghum and Pearl Millet Diseases III. September 23-30, 2000. Guanajuata, Mexico (in press).

Greneir, C., G. Ejeta, P. Bromel, J. Dahlberg, A.El Ahmadi, M. Mahmoud, G. Peterson, and D. Rosenow. 2001. Sorghums of the Sudan; Importance and Diversity. American Society of Agronomy Abstracts. CD-ROM. October 21-25, 2001, Charlotte, North Carolina.

Germplasm Enhancement for Resistance to Insects and Improved Efficiency for Sustainable Agriculture Systems

Project TAM-223
Gary C. Peterson
Texas A&M University

Principal Investigator

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Collaborating Scientists

Dr. J. van den Berg, Entomology, ARC - Grain Crops Institute, Private Bag X1251, Potchefstroom 2520, Republic of South Africa

Ing. Rafael Obando, Sorghum Breeding, Instituto Nicaragense de Tecnolog, Edificio Mar, Apdo.1247, Managua, Nicaragua

Ing. Rene Clara, Sorghum Breeding, CENTA, Apartado Postal 885, San Salvador, El Salvador

Dr. Medson Chisi, Sorghum Breeding, Golden Valley Research Station, Box 54, Fringila, Zambia

Dr. Pharoah Mosupi, Entomology, Department of Agricultural Research, Private Bag 0033, Gaborone, Botswana

Dr. Neal McLaren, ARC-Grain Crops Institute, Private Bag X1251, Potchefstroom 2520, Republic of South Africa

Dr. Aboubacar Toure, Sorghum Breeding, IER, Sotuba, B.P. 438, Bamako, Mali

Mr. Sidi B. Coulibaly, Agronomy/Physiology, IER, Sotuba, B.P. 438, Bamako, Mali (currently Graduate Research Assistant, Texas A&M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79403-9803)

Dr. Bonnie B. Pendleton, Entomology, Division of Agriculture, West Texas A&M University, Canyon, TX 79016 (WTU-200)

Dr. W.L. Rooney, Sorghum Breeding, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (TAM-220C)

Dr. Lloyd Rooney, Cereal Chemistry, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (TAM-226)

Dr. D.T. Rosenow, Sorghum Breeding, Texas Agricultural Experiment Station, Texas A&M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79403-9803 (TAM-222)

Summary

Increase Yield and Promote Economic Growth

Primary research emphasis of this project is the breeding for resistance to insects component of the integrated Texas A&M University sorghum improvement program. Project objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars, germplasm, or parental lines resistant to selected biotic and abiotic stresses. Insect pests receiving major emphasis are the sorghum midge (*Stenodiplosis sorghicola*), greenbug (*Schizaphis graminum*), and sugarcane aphid (*Melanaphis sacchari*). Segregating populations are also selected for resistance to economically important diseases including but not limited to: sorghum downy mildew (caused by *Peronosclerospora sorghi* (Westan and Uppal) Shaw), head smut (caused by (*Sphacelotheca reiliana* (Kuhn) Clinton), anthracnose (caused by *(Colletotrichum graminicola* (Cesati) Wilson). Other diseases for which resistant genotypes are selected include zonate leaf spot (caused by (*Gloeocercospora sorghi* Bain and Edgerton), bacterial leaf streak (caused by *Xanthomonas holcicola* (Elliot) Star and Burkholder), bacterial leaf stripe (caused by *Pseudomonas andropogoni* (E.F. Smith) Stapp), and charcoal rot (caused by *Macrophomina phaseolina* (Tassi) Goid).

Breeding and selection activities primarily use conventional methodology. Collaborative molecular biology research has mapped genes for resistance to greenbug biotypes and molecular markers are being used to concurrently select for greenbug resistance and stay green (post-flowering drought tolerance). Numerous lines from different populations are being evaluated to identify superior lines resistant to greenbug biotype I with excellent stay green and wide adaptation.

A primary research objective is to develop sorghum midge resistant hybrid parental lines. In addition to pest re-

sistance, the lines should produce excellent grain yield under high pest density, acceptable yield with the pest absent, and contain other favorable traits including adaptation, disease resistance, etc. The best midge-resistant lines currently available in the breeding program in hybrid combination produce 10-15% grain yield than the best susceptible hybrids when sorghum midge are absent at anthesis. When sorghum midge are present at anthesis the resistant hybrids produce significantly more grain than susceptible hybrids. Research is on-going to select for improved grain yield potential.

Increase Yield, Promote Economic Growth, Improve Nutrition

The greenbug resistance program has lines in advanced yield testing with excellent resistance. Many of the lines possess wide adaptation and resistance to several diseases. Included is an array of plant and grain color combinations including tan plant, white grain and tan plant, and red grain. Breeding lines with multiple stress resistance and tan plant with white or red grain may help increase utilization of sorghum in new or non-traditional uses. The multiple stress resistance, wide adaptation, diverse plant types will contribute to utilization by private industry after release.

Improve Institutional Capacity

The principal investigator serves on the graduate committee of one M.S. student (from Mali), and two Ph.D. students (co-chair of Malian student at Texas Tech and U.S. student at Texas A&M University). The principal investigator coordinated the short-term training of collaborators from El Salvador and Nicaragua, and initiated the process of providing short-term training opportunity to a Southern Africa collaborator. The principal investigator presented a seminar at the Botswana College of Agriculture on INTSORMIL objectives and goals, and on TAM-223 research.

Objectives, Production and Utilization Constraints

Objectives

- Obtain and evaluate germplasm for resistance to arthropod pests.
- Determine the inheritance of insect resistance, and the resistance source or mechanisms most useful to sorghum improvement.
- Develop and release high yielding, agronomically improved sorghums resistant to selected insects.
- Utilize molecular biology to increase understanding of the genetics of plant resistance traits.
- Develop and release high grain yield sorghums with multiple stress resistance and improved grain quality traits.

Constraints

Sorghum production and yield stability is constrained by biotic and abiotic stresses including insects, diseases and drought. Insects pose a risk in all sorghum production areas with damage depending on the insect and local environment. To reduce stress impact sorghum cultivars with enhanced environmental fitness suitable for use in sustainable production systems are needed. Cultivars experience stress concurrently or sequentially and genetic resistance to multiple stresses will reduce environmental risk and enhance productivity. This is especially important as production ecosystems change due to technology improvements with the natural balance between cultivars and biotic stresses changing and insect damage becoming increasingly severe.

Genetic resistance may be utilized at no additional producer cost to meet the demands of increased food production in economically profitable, environmentally sustainable production systems. This requires a multi-disciplinary research program to integrate resistant genotypes into the management system. Varieties or hybrids with genetic resistance to stress readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Research Approach and Project Output

Research Methods

Collaborative LDC research is supported through graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas. Activity is conducted in three regional programs - Southern Africa, Central America, and West Africa (Mali). Project resources previously directed to Mali have been reallocated to other sites with current activity primarily to support a Ph.D. student. Southern Africa research is directed at incorporating resistance to sugarcane aphid into adapted cultivars, and includes disease resistance, adaptation, and end-use traits. Nicaragua and El Salvador provide additional research on sorghum midge (the most important biotic production constraint in Nicaragua), drought resistance, disease resistance, adaptation, and end-use traits. In the United States, sorghum midge and greenbug-resistant sources have been identified and used in developing elite resistant sorghums. Primary emphasis is on biotype I greenbug resistance. Through collaborative ties with other projects genetic inheritance, resistance mechanisms, molecular mapping, and marker-assisted selection research has been conducted. Appropriate selection methodology is used to concurrently select for other biotic or abiotic stress resistance to develop germplasm with wide adaptation, multiple stress resistance, and improved end-use traits.

Germplasm is evaluated for resistance to economically important insects in field nurseries or greenhouse facilities depending on the insect mode of infestation. Sources of germplasm for evaluation are introductions from other programs (including ICRISAT), exotic lines, and partially or fully converted exotic lines from the sorghum conversion program. New resistance sources are crossed to elite resistant germplasm, and to other germplasms with superior trait(s). Although a primary selection criteria is insect resistance, selection criteria include wide adaptation, resistance to specific diseases, drought resistance, weathering resistance and improved end-use traits. Based on data analysis and phenotypic evaluation, crosses are made among elite lines to produce germplasm for subsequent evaluation. The goal is to combine resistance genes for multiple stress into a single high yielding genotype.

For insects important in LDC's but not in the U.S., germplasm is provided to the LDC cooperator. The germplasm is evaluated for resistance to the specific insect under the local production system (fertilizer, tillage, plant population, etc.), and/or greenhouses, and agronomic and yield data collected if possible. The populations are grown in the U.S. and selected for adaptation.

Research Findings

Sorghum Midge Resistance

Research to identify new superior A- or R-lines continued. In 2001, a replicated line test (85 entries x 3 replications) was grown in 7 planting dates and four locations. A replicated hybrid test (60 entries x 3 replications) was grown in 5 planting dates at three locations. Additionally, the midge line test was grown at the INTA research station near Managua, Nicaragua to evaluate for adaptation to local conditions, and at Potchefstroom, South Africa to evaluate for adaptation and resistance to sugarcane aphid. Partial results are reported in Table 1. Sorghum midge density in Texas was abnormally low during the 2001 summer resulting in average midge damage ratings of less than 2.0 (corresponding to less than 20% seed loss) in most planting dates. Many entries were identified with excellent resistance to the low population density. However, these entries may not be resistant under high or moderate population density. Based on agronomic desirability in Texas, 37 entries were selected for additional evaluation. At the INTA station near Managua, Nicaragua, population density was also low. There was generally a good correspondence between sorghum midge resistance in Texas and in Nicaragua. Several entries were identified with generally good midge resistance in Texas and Nicaragua, and good grain yield in Nicaragua.

Grain yield potential of elite breeding lines in hybrid combination was evaluated in 5 environments - Corpus Christi normal (CA), Corpus Christi medium-late (CM), Corpus Christi late (CL), Lubbock (L), and Halfway (H). Partial results are shown in Table 2. Because of environmental conditions few midges were present at anthesis and midge damage ratings are not reported. The standard resistant check is ATx2755*Tx2767 and the standard susceptible checks are ATx2752*RTx430 and ATx399*RTx430. Grain yield was variable due to harsh environmental conditions at Corpus Christi and Halfway. Susceptible hybrids

Table 1. Mean midge line test sorghum midge damage, and grain yield at Managua, Nicaragua and sorghum midge damage at Corpus Christi and College Station, TX, 2001.

	Midge Damage Rating†					
	Corpus Christi		College Station		Nicaragua	Grain Yield
Designation	Early	Late	Early	Late		Kg ha^{-1}
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550610))))))-PR2-LG4-der	1.0	1.0	1.0	2.5	1.0	6344.00
(MR102-90M2*IS3546C/SC751-14)-SM3-CM3-CM1-SM1-CM1-CMBK	1.3	1.0	1.5	1.0	1.0	5838.00
B8PR1013	3.0	2.0	1.5	2.5	1.0	5322.00
(Tx430*MR112B-92M2)-SM29-	1.3	1.3	1.0	1.0	1.0	5140.00
B9PR2143	1.7	1.3	3.5	4.0	1.0	4780.00
B0PR11	1.0	1.7	1.0	2.0	1.5	4566.00
(PM12713*Tx2882)-CM7-CM1-	1.0	1.0	1.0	2.0	1.5	4470.00
(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG2-CG2-CM2	1.0	1.0	2.0	6.5	1.5	4462.00
(Tx2882*SRN39)-CM3-SM2-SM2-SM2	1.0	1.0	1.0	1.5	2.0	4373.00
9MLT157	1.0	1.3	1.5	2.0	1.5	4262.00
(MR112B-92M2*Tx2880)-SM3-SM1-	1.0	1.0	1.0	1.0	1.0	4197.00
(Tx2880*(Tx2880*(Tx2864*Tx436*(Tx2864*PI550607)))))-PR3-SM6-CM3-CM4	1.0	1.3	1.0	2.0	3.5	4167.00
(PM12713*Tx2882)-CM3-CM2	1.0	1.0	1.0	1.0	2.0	4164.00
MB108B/P.G.	1.0	1.7	1.5	2.5	2.0	4112.00
(MB110-B92NF3*BTx631)-SM11-SM1-SM1-CM2-CM1	1.3	1.7	1.5	4.0	1.0	4070.00
(BArg34*MB120C-BM5)-SM3-	3.3	1.7	1.5	1.5	1.0	4011.00
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550610))))))-PR2-LG4-der	1.0	1.3	1.0	2.5	1.5	3292.00
(Tx2882*SRN39)-CM3-SM2-SM2-CM1	1.0	1.0	1.0	2.0	1.5	3806.00
B8PR1021/MB116C	2.0	1.0	1.5	1.0	2.0	3775.00
Tx2767	1.0	1.3	1.5	1.5	1.0	3775.00
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550610))))))-PR2-LG4-der	1.0	1.0	1.0	2.0	1.0	3757.00
(PM12713*Tx2882)-SM8-CM1	1.0	1.0	2.0	1.5	4.0	3748.00
MEAN	1.4	1.5	1.8	3.0	2.0	1.89
LSD	1.0	1.2	1.2	1.5	1.5	0.8

† Rated on scale of 1 = 0-10% damaged kernels, 2 = 11-20% damaged kernels, up to 9 = 91-100%.

Table 2. Grain yield and days to 50% anthesis of selected entries in the 2001 Midge Hybrid Test.

Hybrid	Status[1]	Grain Yield				
		Corpus			Lubbock	Halfway
		Late	Medium-Late	Normal		
		lb/ac				
ATx399*Tx430	S-CK	1221	1480	700	1777	439
ATx2755*97M14		1119	1053	669	1797	1392
A8PR1013*MB108B		1074	1189	459	1664	501
ATx2752*Tx2862	S-CK	1069	1247	948	2225	787
A0PR11*Tx2882		1013	1170	967	1589	698
ATx2755*97M9		999	876	778	1467	636
A8PR1011*9MLT180		989	995	792	1620	434
A8PR1013*Tx2882		962	826	398	1729	718
A8PR1013*9MLT164		923	844	410	1841	774
A8PR1011*MB108B		917	1674	873	1667	488
A8PR1019*Tx2882		903	911	740	1569	1270
A8PR1011*Tx2880		897	899	406	1610	864
A8PR2145*Tx2882		897	1253	677	1503	1174
ATx2755*MB108B		881	1466	798	1836	447
A8PR1013*Tx2880		876	999	566	1554	834
A8PR1011*9MLT157		872	879	755	1313	1031
A0PR13*Tx2880		870	1244	1214	1406	1200
A8PR1015*Tx2880		865	1837	1139	2189	1187
A8PR1013*9MLT180		848	1064	656	1466	886
A0PR15*Tx2880		844	1261	1043	1967	592
A35*Tx430	S-CK	839	1901	1125	1273	279
A0PR11*Tx2880		827	1313	938	1815	792
ATx2752*Tx2783	S-CK	821	1292	989	2039	426
A8PR1011*9MLT164		814	853	496	1643	880
A9PR2141*Tx2880		812	873	650	1304	722
ATx2755*97M17		810	1099	625	1396	1116
A8PR1013*9MLT176		806	781	558	1015	704
ATx2755*Tx2882	R-CK	778	891	530	1596	723
ATx2752*Tx430	S-CK	766	567	949	2026	633
A1*Tx430	S-CK	745	967	854	1527	942
A35*Tx2862	S-CK	663	1447	1179	1764	366
ATx2755*Tx2767	R-CK	607	925	515	1863	856
ATx2755*Tx2880	R-CK	596	838	545	1398	1277
A1*Tx2862	S-CK	574	592	786	2120	994
MEAN		1696	2401	1733	3651	1745
LSD .05		556	817	839	1071	925

[1] R = resistant; S = susceptible; Ck = check.

generally produced more grain than resistant hybrids although differences were not consistent. Some resistant experimental hybrids produced grain yield not significantly different than some susceptible hybrids depending on the environment. Results confirm previous observations - most resistant hybrids will not produce grain yield equal to susceptible hybrids in plantings where no or few midges are present. The line designated 8PR1013 has a large open panicle with white grain and possess excellent resistance. It was selected for inclusion in the PROFIT (Productive Rotations On Farms In Texas) hybrid seed project.

Greenbug Resistance

Selections to develop germplasm resistant to biotype I and K greenbug were made. The primary resistance sources are PI550607 and PI550610. Both sources are used in developing R-lines, and PI550610 is used in B-line development. Screening against the greenbug biotypes identified genotypes that express moderate resistance. Biotype resistance is conditioned by different genes and a moderate level of resistance is desired. Crosses to introgress resistance gene(s) into other germplasm were made.

New R-lines resistant to biotype E and/or I produced excellent hybrids. The lines represent a range of plant types including tan plant, white pericarp and tan plant, and red pericarp. New tan plant, red grain biotype E resistant A-lines were evaluated in hybrid combination. The hybrids expressed excellent grain yield potential, wide adaptation and resistance to several diseases. Based on performance one A-line, 8PR1059, and two restorer lines, 5BRON139 (resistant to biotype E) and LG35 (resistant to biotype E/I/K) were selected for inclusion in the PROFIT hybrid program.

A 120-entry observation of experimental hybrids was provided to INTA, Nicaragua, to evaluate for adaptation. Hybrids represent a range of plant types including different plant color and grain color combinations, and most pollen (male) parents have excellent disease resistance. Many experimental hybrids produced excellent grain yield and appear to be well adapted to the local production system. (partial data Table 3). Additional evaluation will continue in 2002.

Sugarcane Aphid Resistance

The sugarcane aphid (*Melanaphis sacchari*) is an insect pest of sorghum throughout Southern Africa. Previous col-

Table 3. Mean grain yield and selected agronomic of experimental hybrids, Managua, Nicaragua, 2001.

Designation	Days to 50% Anthesis	Height	Excertion	Panicle length	Grain yield
A0PR59*6OBS143	64	143	8	39	9265
ATx635*5BRON156	65	166	15	26	7341
A8PR1053*6BRON167	65	137	5	37	6514
A8PR1053*Tx430	59	161	11	34	6476
A8PR1057*6BRON167	65	137	9	34	6333
A8PR1051*Tx430	59	152	12	38	5892
A8PR1057*Tx2862	65	136	5	31	5889
A0PR51*5BRON131	62	134	11	35	5696
A0PR51*Tx430	61	135	7	35	5646
A8PR1059*Tx430	59	158	6	32	5633
A8PR1057*LG35/8LI161	65	145	8	34	5633
A807*6BRON167	66	130	15	37	5482
ATx631*6BRON167	65	171	14	40	5398
A8PR1059*Tx2862	64	147	9	32	5396
ATx635*5BRON131	65	149	8	34	5284
A8PR1053*Tx436	57	142	12	40	5182
A8PR1059*Tx436	64	160	13	24	5166
A8PR1051*6OBS143	67	149	5	44	4940
A91NF18*Tx2783	66	143	8	26	4918
A91NF18*5BRON151	60	158	8	40	4885
ATx635*5BRON139	64	185	14	36	4864
A8PR1057*5BRON131	59	136	9	31	4845
A8PR1053*98LI159	66	155	9	38	4750
A8PR1045*Tx2862	65	139	10	33	4750
ATx631*6OBS124	60	195	13	34	4672
ATx2752*5BRON151	58	142	12	34	4635
A8PR1045*Tx2783	66	180	13	27	4450
A8PR1051*Tx436	57	145	9	41	4449
A8PR1057*5BRON155	66	147	11	33	4391
A35*5BRON151	61	144	23	34	4293

laborative research between TAM-223, TAM-225 (discontinued), and the Botswana Department of Agricultural Research (DAR), identified several sources of resistance and studied the inheritance of resistance. The program now includes South African (ARC-Potchefstroom) collaborators. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, FGYQ336 have been intercrossed, crossed to locally adapted cultivars (include Segeolane, Marupantse, Macia, Town, SV1, and A964), and crossed to elite lines from the Texas program to develop a range of populations. The segregating populations are planted at Beeville and Lubbock, Texas for selection. Evaluation for sugarcane aphid resistance and adaptation to local environments is done at Potchefstroom, South Africa or Gaborone, Botswana.

A 100-entry test for sugarcane aphid resistance was developed and sent to South Africa and Botswana. The test was evaluated for aphid resistance, adaptation, and weathering resistance in replicated tests at the ARC, Potchefstroom, and for aphid resistance and adaptation at the ARC Lowveld Station near Hazyview (Table 4). Thirty experimental entries sustained aphid damage less than or equal to several resistant checks (WM#322, Ent. 62/SADC, FGYQ353, TAM428). Forty-three entries were selected for additional evaluation based on aphid resistance and adaptation. The breeding lines will undergo additional selection in Texas, and screening and agronomic evaluation in Southern Africa. Varieties developed should contain wide adaptation, sugarcane aphid resistance, disease resistance (primarily sooty stripe and anthracnose), and other favorable traits including tan plant, white pericarp, and appropriate height and maturity. Several experimental entries may have potential use as varieties. Additional studies will be conducted to accurately access the yield potential, agronomic acceptability, and food use potential.

The midge line test (and 85-entry test) was also evaluated for resistance to sugarcane aphid. Sorghum midge population density at anthesis was not sufficient to evaluate for midge resistance. However, ratings obtained in Texas give an accurate measure of the sorghum midge resistance level. Experimental entries were identified with sugarcane aphid damage less than the test mean and sorghum midge damage (in Texas) of 20% or less.

Greenbug Resistance/Stay-green Study

Marker-assisted selection research for greenbug resistance and stay green (post-flowering drought tolerance) continued. This is a collaborative research activity between this project, TAM-222, and the molecular biology laboratory of Dr. Henry Nguyen (formerly at Texas Tech University and now at the University of Missouri). Mr. Sidi

Table 4. Mean sugarcane aphid damage ratings and weathering resistance, 2002.

	Damage rating†		Weathering‡
Pedigree	Potchefstroom	Hazyview	
(MR112B-92M2*Tx2880)-SM3-SM1-ML52	0.0	1.3	-
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-CG3-BGBK	1.0	1.0	3.0
(CE151*BDM499)-LD17-BE1	1.0	1.7	3.0
TAM428	1.0	2.0	3.0
(Macia*TAM428)-LL2	1.0	1.0	3.0
(6BRON161/(7EO366*Tx2783)*CE151)-LG2-CG3-BG2	1.3	1.0	2.5
(CE151*BDM499)-LD17-BE2	1.3	1.0	1.0
(SV1*Sima/IS23250)-LG15-CG1-BG2	1.3	1.0	2.5
WM#322	1.3	1.0	3.0
(5BRON131/((80C2241*GR108-90M30)-HG46)*WM#177)-LG1-BGBK	1.3	1.0	2.5
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON-40/E#15/SADC)-LG1-LG1-BGBK	1.3	1.0	1.5
(EPSON2-40/E#15/SADC*TAM428)-CG1-BGBK	1.3	1.0	2.0
FGYQ336	1.3	1.0	2.5
(Segaolane*WM#322)-CG1-BGBK	1.3	1.0	2.5
(6OB124/(GR134B-LG56)*WM#177)-LG7-CG2-BGBK	1.3	1.0	2.0
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BGBK	1.3	1.3	1.0
GR128-92M12	1.7	1.3	2.5
(CE151*TAM428)-LG15-LG1-BG1	1.7	1.0	2.0
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-LG1-BGBK	1.7	1.0	
(6OB128/Tx2862*6EO361)*CE151)-LG4-CG1-BGBK	1.7	1.0	1.0
(Macia*TAM428)-HD1	1.7	2.0	2.5
Sima(IS23250)	1.7	1.0	2.5
(Macia*TAM428)-LL9	1.7	1.0	2.0
(CE151*TAM428)-CG1-BGBK	1.7	1.3	2.0
(CE151*TAM428)-LG1-BGBK	1.7	1.0	2.5
(87EO366*TAM428)-HF2	1.7	1.0	2.0
(6OB128/(Tx2862*6EO361)*CE151)-LG19-CCBK	1.7	1.0	3.5
Ent.62/SADC	1.7	1.0	0.5
PRGC/E#222878	1.7	1.0	2.0
(EPSON2-40/E#15/SADC*6OBS124/94CE81-3/GR134B-LG56-)-LG1-CG1-BG1	2.0	1.0	1.0
FGYQ353	2.0	1.0	2.0
CE151	2.0	1.0	2.0
(6BRON161/(7EO366*Tx2783)*EPSON2040/e#15/SADC)-CG2-BG2	2.0	1.3	2.5
(6BRON126/((87BH8606-14*GR107-90M46)-HG10*CE151)-CG1-BGBK	2.0	1.3	2.5
(6OBS128/94CE88-3/(Tx2862*6EO361)*EPSON2-40/E#15/SADC)-LG1-CG2-BG2	2.0	1.0	0.5
(EPSON2-40/E#15/SADC*TAM428)-LG3-CG1-BGBK	2.0	1.3	2.0
(6OB124/94CE81-3/GR134B-LG56-*WM#177)-LG1-LG1-BG3	2.0	1.0	2.0
SDSL89426	2.0	1.0	2.5
(EPSON2-40/E#15/SADC*A964)-CG3-BGBK	2.3	1.0	1.0
(6OB124/94CE81-3/GR134B-LG56-*WM#177)-CG3-BG1	2.3	1.0	1.0
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR2-CCBK	2.3	2.3	3.5
(Macia*TAM428)-CG2-BGBK	2.3	1.3	3.0
(Segaolane*FGYQ336)-CG5-BGBK	2.3	1.0	2.5
((6BRON126/(87BH8606-14*GR107-90M46))*CE151)-LG2-CG1-BG2	2.3	1.3	2.5
(6OB128/(Tx2862*6EO361)*CE151)-LG3-LG1-BGBK	2.3	1.0	2.0
PRGC/E#222879	2.3	1.0	2.5
((6BRON126/(87BH8606-14*GR107-90M46))*CE151)-LG1-LG1-BG2	2.3	1.3	1.0
(6BRON161/(7EO366*Tx2783)*CE151)-LG4-CG2-BG2	2.3	1.7	1.5
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG1-LG1-BGBK	2.3	1.7	1.5
Mean	2.6	1.5	
LSD .05	1.0	1.1	

[1] Rated on scale of 1 = no damage, 2 = light damage, 3 = medium damage, 4 = heavy damage, 5 = dead plant.
[2] Rated on scale of 0 = no weathering up to 5 = severe weathering.

Bekaye Coulibaly (Mali) is conducting this Ph.D. research to compare the efficiency of marker-assisted selection versus traditional selection methodology. Mr. Coulibaly is completing the dissertation and should return to Mali by October 1, 2002.

Networking Activities

Workshops and Meetings

INTSORMIL Central America Region Research Planning Workshop - 27 to 28 February 2002, Managua, Nicaragua

Participated in the 2002 Sorghum Industry Conference, 17-19 February 2002, San Francisco, CA

Research Investigator Exchanges

Coordinated training program of Ing. Rene Clara (El Salvador), Ing. Hector Deras (El Salvador), and Ing. Rafael Obando (Nicaragua), July-August, 2001.

Interacted with private seed company scientists and Texas Grain Sorghum Association representatives on several occasions as part of the Texas Agricultural Experiment Station (TAES) Sorghum Advisory Committee.

Interacted with sorghum farmers and Texas Grain Sorghum Association representatives on several occasions as TAES PROFIT (Productive Rotations On Farms In Texas) coordinator.

Participated in Sorghum Germplasm Committee meeting, 18 February 2002, San Francisco, CA. Interacted with private scientists and USDA scientists and administrators on issues related to germplasm.

Botswana, Zambia, and South Africa - 31 March to 14 April 2001. In Botswana met with Department of Agricultural Research scientists to plan future research activity. Met with Botswana College of Agriculture administrators and scientists to discuss initiating additional collaborative research in plant breeding and entomology, and potential in other disciplines. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss sorghum and pearl millet research. Evaluated sorghum research plots at Golden Valley and Siavonga region. Discussed INTSORMIL Southern Africa activity with USAID/Zambia representatives. In South Africa, met with collaborators at the ARC, Potchefstroom, to evaluate collaborative activity and plan future research. Evaluated sorghum research plots at the Cedera Research Station near Hilton, the ARC at Potchefstroom, and the Lowveld Station near Hazyview. Also met with Dr. John Taylor at the University of Pretoria to discuss sorghum and pearl millet grain quality research.

Arranged the travel of Mr. Leo Mpofu to Zambia to interact with regional scientists and the visiting INTSORMIL team, 4-12 April 2002.

Participated in the Crop Germplasm Committee Chairs meeting, 4-5 June 2002, Beltsville, MD. Discussed germplasm issues with crop curators, Regional Station Directors, NSSL personnel, and USDA-ARS administrators.

Germplasm and research information exchange

Germplasm Conservation and Use

Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Mali, Senegal, Ghana, Nicaragua, El Salvador, South Africa, Botswana, Zimbabwe, and Zambia. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.

The following TAM-223 developed experimental lines were used as hybrid seed parents in the summer of 2001: sorghum midge resistant: Tx2880 and A8PR1013; biotype E greenbug resistant: 5BRON139, A8PR1059, biotype E/I greenbug resistant: LG35. Seed was provided to a private seed company to produce hybrids for wide area testing in 2002 as part of the PROFIT (Productive Rotations On Farms In Texas) initiative.

Germplasm previously developed and released by this project is used by commercial seed companies in hybrid production.

Participated in short- or long-term training of collaborators from Mali, Nicaragua and El Salvador. Serving on M.S. committee of N. Teme (Mali), and co-chair of S.B. Coulibaly (Mali). Coordinated training program of Ing. Rene Clara (El Salvador), Ing. Hector Deras (El Salvador), and Ing. Rafael Obando (Nicaragua), July-August, 2001.

Other Cooperators

Collaboration with the following scientists was important in the activities of TAM-223:

Mr. Leo Mpofu, Department of Research and Specialist Service, Matopos Research Station, P.O. K5137, Bulawayo, Zimbabwe

Dr. R. D. Waniska, Cereal Chemistry, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843

Dr. G.N. Odvody, Plant Pathology, Texas Agricultural Experiment Station, Texas A&M University. Agricultural Research and Extension Center, Route 2 Box 589, Corpus Christi, TX 78406-9704

Dr. R.G. Henzell, Sorghum Breeding, Hermitage Research Station, via Warwick, QLD 4370, Australia

Publications and Presentations

Abstracts

Rosenow, D.T., N. Teme, C.A. Woodfin, G.N. Odvody, and G.C. Peterson. 2000. Relationship of stay-green with charcoal rot and lodging in sorghum. *In* Proc. of Global 2000: Sorghum and Pearl Millet Diseases III. Guanajuato, Mexico, Sep. 23-30, 2000. (In Press).

Presentations

Peterson, G.C., B.B. Pendleton, and G.L. Teetes. 2000. PROFIT - Productive Rotations On Farms In Texas: A New Paradigm for Sorghum Research and Information Delivery. *In* Proc. of Global 2000: Sorghum and Pearl Millet Diseases III. Guanajuato, Mexico, Sep. 23-30, 2000. (In Press).

Refereed Journal

Katsar, C.S., A.H. Paterson, G.L. Teetes, and G.C. Peterson. 2002. Molecular analysis of sorghum resistance to the greenbug significantly involved in conceptualizing and implementing the extension process, and participated in the grant presentation that resulted in a five-year extension of INTSORMIL.

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF-212
Bruce R. Hamaker
Purdue University

Principal Investigator

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Collaborating Scientists

Mr. Kaka Saley, Cereal Scientist; Moustapha Moussa, Cereal Technologist; Dr. Adam Aboubacar, Cereal Technologist; Ms. Ramatou Seydou, Chemist; Mr. Moussa Oumarou, Chemist; Dr. Issoufou Kapran, Sorghum Breeder; INRAN B.P. 429, Niamey, Niger

Ms. Senayit Yetneberk, Food Technologist, IAR, Nazret Research Station, P.O. Box 436, Nazret, Ethiopia

Ms. Betty Bugusu, Food Technologist, KARI, Katumani National Dryland Farming Research Center, P.O. Box 340, Machakos, Kenya

Dr. Arun Chandrashekar, Cereal Chemist, CFTRI, Department of Food Microbiology, Mysore 570013, India; Dr. D.S. Murty, Mahyco Research Foundation, Hyderabad, India

Dr. Gebisa Ejeta, Sorghum Breeder; Dr. Robert Elkin, Poultry Nutritionist; Ms. Chia-Ping Huang, Cereal Chemist; Ms. Debra Sherman, Microscopist; Dr. Moustapha Benmoussa, Plant Molecular Biologist, Purdue University, West Lafayette, IN 47907

Dr. Brian Larkins, Plant Molecular Biologist, University of Arizona, Tucson, AZ

Summary

Our work has continued to focus on the nutritional quality traits of sorghum grain related to protein and starch digestibility in human food and animal feed, and also fundamental aspects of the grain related to its use in food. An overall objective is to find ways to improve sorghum so that it becomes more nutritious and competitive to other major cereal grains. In Niger, work continues towards commercialization of sorghum and millet agglomerated products (couscous and other similar particle size foods) and high quality flours. While we have not worked much on millet in our U.S. studies, there is now a somewhat greater emphasis on millet research and technology at the regional level with the addition of collaborators in Maiduguri, Nigeria who work on millet hybrid development, their quality, and products made from them.

In this year, a study was expanded on factors that cause lower cooked sorghum starch digestibility (and digestion rate) compared to other cooked cereal porridges. Sorghum lines were tested that exhibited a broad range of protein digestibilities – from 23 to 76% for a one hour pepsin digestion – that included high protein digestibility mutant lines and low to high digestibility normal lines. They were compared to maize and rice. Decorticating the sorghum grain and defatting the flour significantly increased starch digestibility in all samples by a similar margin (including other cereals). Notably, protease pretreatment resulted in significant increase in starch digestibility in all samples except for the normal sorghums. The highest increase was observed in the high protein digestibility cultivars (14-19%) followed by the maize control (8%) and rice (7%). These results showed that non-starch flour components contribute to low starch digestibility and low protein digestibility seems to be the single largest contributor. The relatively high starch digestibility of the high protein digestibility mutant lines suggest that this sorghum would be beneficial for use in foods such as for weaned infants where energy and protein recovery are important. However, improvement in grain quality of the high protein digestibility mutant lines is critical for their future use.

As reported last year, grain have been identified in progeny of crosses of the mutant to hard endosperm lines that are normal in appearance and contain the abnormal protein body structure typical of the high digestibility mutant. This has now been found both in the Purdue breeding lines and those coming out of the India project funded through Mahyco Research Foundation. Yet, difficulties still exist in consistency of grain quality within a panicle and the issue of stability of the trait. We are initiating a new project this year at Purdue in breeding and chemistry to work on this problem. Two collaborator studies have been completed on feed use of the high protein digestibility sorghum. A published study on its use in chickens showed substantially higher true amino acid digestibilities in the mutant, as well as one sorghum hybrid, compared to the normal parent or maize. A study (in press) using a least-cost feed mix linear programming model to examine the benefit of high protein digestibility sorghum shows, under certain situations, potential advantage of using the sorghum in poultry feed. Combina-

tion with improved starch digestibility would make the grain even more competitive, and this is our goal.

Chemical studies on sorghum grain components have shown that sorghum starch structure appears to be somewhat different from that of maize or rice, and may begin to explain differences in the way sorghum behaves in processed foods. Sorghum amylopectin, the large branched starch molecule, was shown to have a structure such that it may retrograde (reassociate) more extensively than in rice or maize. This would lead to increased rates of staling and thick gels on cooling. This research is a step in trying to find ways, either through breeding or processing, to improve basic grain properties for traditional and processed foods.

Activities regarding the sorghum/millet processing unit in Niger and work towards commercialization of couscous and other products continued. A large market test was completed and results are currently being analyzed. Collaboration with a few local entrepreneurs has led to marketing of products in stores.

Objectives, Production and Utilization Constraints

Objectives

- Determine the relationships among the physical, structural, and chemical components of the grain that affect the food and nutritional quality of sorghum and millet.
- Determine the biochemical basis for the relatively poor protein and starch digestibility of sorghum grain and many cooked sorghum products.
- Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum and millet grain.
- Optimize processes and improve quality of commercializable sorghum and millet processed foods, and facilitate transfer of technologies.

Constraints

Research on food and nutritional quality of sorghum and millet grains is necessary to improve grain quality characteristics and stimulate commercial processing in developing countries. Factors affecting milling qualities, food quality, and nutritional value critically affect other efforts to improve the crop. If the grain is not acceptable to consumers, then grain yield and other agronomic improvements to the crop are likely to be lost. In addition, breeding grains that have superior quality traits will more probably give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum that is perceived by some to have comparably poor quality characteristics to other major cereals. The overall goal of this project is to improve food and nutritional quality of sorghum and millet through a better understanding of the structural and chemical components of the grain that affect quality. This knowledge will be applied to develop useful methodologies for screening germplasm for end-use quality, develop techniques to make the grain more nutritious, and improve grain utilization through processing.

Research Approach and Project Output

Couscous and High Quality Flour Processing

Work continues towards developing and marketable sorghum and millet processed products in Niger and neighboring countries, and working with local entrepreneurs to encourage commercial production. Our goal is to combine research, marketing testing, and entrepreneurial training and demonstration to stimulate the processing of high quality, competitive products for urban areas. Over the past six years INRAN/Niger Food Technology Laboratory and PRF-212 have worked together to set up in Niamey an entrepreneurial-scale agglomerated products (mainly couscous) and flour processing unit. In 1995, the core of the sorghum/millet processing unit was installed at INRAN; consisting of a central mechanized agglomerator designed and fabricated at CIRAD, France by J. Faure, a mixer for flour wetting, a couscousierre (steamer), a small solar drier with through ventilation powered by a solar cell (fabricated in Niamey by ONERSOL), and a sealer for packaging. Since that time, a much larger passive solar drying unit was built at INRAN to dry approximately 200 kg couscous every 2 days. Currently that solar drying, which is the largest of its kind in Niamey, is being improved by the addition of a better-fitting and completely waterproof top. As high quality flours are essential to make quality couscous, a small-scale commercial grain decorticator (dehuller) and hammer mill (Urpata Sahel, Dakar) were procured through PRF-212 to complete the unit. The INRAN food technology group has in the past year also developed high quality flours as commercially viable products.

A strong and continued working relationship with the sorghum breeding program of Kapran-INRAN/ Axtell-Purdue has been important to this project. Their released hybrid, NAD-1, and now a second generation tan plant hybrid (still in the experimental phase) are being used to produce processed products. Over the last two years NAD-1 agglomerated products (fine couscous (or *dambou*), medium couscous, and the coarse particle-size product *degue*) and high quality decorticated flour have been produced by the unit in large quantities for a two part in-home consumer test and marketing study. This effort was assisted by economists C. Nelson (INTSORMIL) and J. Ndjeunga (ICRISAT/ Mali). Results from the consumer test were reported in the 2001 annual report and showed high acceptability and market potential for the products. The market test, which examined sales and pricing in three market outlets (supermarket, small store, and marketplace) is now completed and data and analysis will be reported next year. We hope that results will support making the case for sorghum/millet processing units to be placed in the commercial sector either through financing from entrepreneurs or seed funding to be sought from granting or loan agencies. An added objective of the project is to stimulate demand for sorghum hybrids through processed products sold in the marketplace. The advantage of the hybrid to a processor is a ready supply of pure source grain, which is a prerequisite to processing high quality commercial products. In an effort to extend these process technologies to interested entrepreneurs, the INRAN Cereal Technology group has formed an association with local food processors. Currently, INRAN is working with a few local entrepreneurs to distribute some products into the marketplace.

Fundamental Studies on Porridge Properties

Sorghum porridges have fundamental properties that differ somewhat from porridges made from other cereal grains. Often sorghum porridges are characterized as comparably thick pastes (this may be desirable) that may form rather stiff gels that, depending on variety used, often do not have good keeping quality. Flat breads made from sorghum, such as kisra, injera, and roti may be of high quality, but tend to go stale rather quickly when stored. We are interested in the fundamental nature of sorghum grain components that makes sorghum grain behave as it does, and accordingly how these traits can be manipulated through genetics or processing.

Studies on the Fine Structure of Sorghum Starch

Because starch is the major component of sorghum grain, several studies have focused on relating its properties to the quality of sorghum food products. In most of these studies, determination of amylose content has been the only chemical test done on sorghum starch. Amylopectin, the major component of starch that is large and highly branched, has not been extensively studied to determine its relationship to nutritional quality and functionality in sorghum-based foods. Amylopectin fine structure has been shown to strongly influence the texture of food products in other cereal grains. “Fine structure” refers to the length or degree of polymerization (DP*n*) of the linear chains in the highly branched amylopectin molecule, the proportion of long, medium, and short chains in the molecule, and the resulting degree of branching. In this study, amylopectin was isolated from starch of eight sorghum genotypes and debranched with isoamylase to obtain linear chains. A trimodal distribution of chains (fractions) was obtained when isoamylase debranched amylopectins were fractionated on a Bio-gel P-10 chromatographic column. Fraction I (FrI) is a high molecular weight, long chain length component of amylopectin. The second (FrII), and third (FrIII) fractions are composed of intermediate, and short chain length molecules, respectively. The chain length of the fractions ranged from DP*n* 60 to 92, from DP*n* 40 to 49, and from DP*n* 16 to 17, for the long, intermediate, and short chain components, respectively. In our experiments, these values were somewhat higher than those reported for other cereal grains such as maize, rice, and wheat and suggest higher degree of crystallinity and tendency to retrogradation in sorghum starch. High extent of retrogradation can mean harder gels from stored pastes, more rapid staling in composite breads containing sorghum or in flatbreads, and in general poorer keeping quality of sorghum-based foods.

The proportions of the linear chains also differ among sorghum genotypes. They ranged from 8.5 to 12.3%, from 17.5% to 23.1%, and from 64.2 to 71.7%, for the long, intermediate, and short chain components, respectively. Although smaller in proportion, the long chain component of amylopectin has considerable effect on some functional properties of starch. It has been shown to affect the viscosity, pasting behavior, retrogradation tendency of starch mixtures as well as the texture of cereal foods. The differences in chain length parameters of amylopectins suggest differences in granular crystalline pattern among the starches. In future studies, we will investigate whether these differences explain at least in part why sorghum has lower starch digestibility than other cereal grains.

How can these and other fundamental studies impact the quality of sorghum-based foods? If variability exists among sorghum cultivars in amylopectin fine structure, as we have found for maize and rice, and its relationship to food quality attributes can be further established, the possibility then exists to develop cultivars with fundamentally improved quality traits. This is important to make sorghum a more utilized grain in processed as well as traditional foods for urban consumers.

Three-Component Complex Affects Paste Viscosity

Studies were completed on a unique three-component complex we identified that was found in sorghum porridge. This high molecular weight complex (in the range of 1 million Daltons) consists of starch amylose, soluble protein, and free fatty acids and was found to markedly increase the viscosity of warm (about 50^{o}C) pastes. Free fatty acids, generated from lypolysis of triacylglycerols (typical fats), were formed fairly rapidly in stored sorghum flours (1 month at 20-25^{o}C) compared to maize flour, and might be expected to be present at earlier times at higher temperatures. High paste viscosities at eating temperatures could be caused in part by incompletely decorticated flour that has been stored, and might be lessened by using only freshly ground flour or flour from well decorticated grain (with lower fat content).

The complex was recreated to enable its verification and further characterization. The amounts of protein and FFA were optimized. The complex was tested for its stability under varying conditions of temperature, pH, and ionic strength. The temperature of formation of the complex was also noted. Defatted sorghum starch, corn starch, pure amylose, whey protein, and linoleic acid were used. Following complexation, the supernatant was filtered and analyzed; stability of the complex was examined by HPSEC using RI and UV detectors. The complex was monitored at room and refrigerated temperatures. It was found to be stable at room temperature for up to 10 days and at refrigerated temperatures for at least 45 days. The temperature of complex formation was observed to be between 60 and 70^0 C. The pH of the complex in solution was found to be 5.9. The pH was varied (3, 8,10), and it was found that, for freshly prepared complex, some of the complex dissociated at pH 3, but it remained intact at pH 10. The three-component complex was water-soluble, but could be precipitated by addition of NaCl (0.01, 0.1 and 1%), indicating the importance of electrostatic charges for its stability. The molar ratios of the three components (in the final mixture) were roughly estimated to be 6 amylose (corn): 2 protein:<300 FFA. Based on these studies and literature data, a model for the organization of the three-component interaction was proposed. These data show an interesting three-component interaction/complexation that occurs in sorghum and other cereal porridges that affect paste viscosity. Large viscosity changes in stored flours may be related to lipolysis and liberation of free fatty acids into the flour system.

Sorghum with High Protein Digestibility

Grain Quality

Studies have continued on the high protein digestibility sorghum mutant that we reported on first in the mid-1990's, albeit more slowly since the passing of John Axtell. As described before, this mutant genotype contains protein bodies with altered morphology consisting of a deeply folded structure that results in a high rate of digestion of the kafirin storage proteins. Our main challenge at this point is to convert the soft, floury kernel background of the mutant to a hard, vitreous kernel phenotype with a consistency of panicle grains and stability of trait for release. In last year's report, it was shown that a vitreous normal-appearing kernel with mutant high digestibility protein bodies can exist together, however consistency and stability of this combination is still uncertain. In the coming year, research with this focus will be re-initiated by Ejeta and Hamaker at Purdue. In India, Murty and Chandrashekar have made progress on the grain quality question through the collaborative project (finished in 2001) funded by Mahyco Research Foundation. Similar results show good quality mutant grain from crosses made with elite Indian germplasm. However, similar to the Purdue program consistency and stability are uncertain.

Cellular Responses to the Mutation

Studies done in collaboration with Dr. Arun Chandrashekar in India provide new information on cellular responses to the mutation. These data will help lead to the mutation source, which would permit more focused breeding efforts as well as understanding of the high digestibility trait. Comparisons have been made between the high protein digestibility sorghum mutant and the *floury2* maize mutant because both have abnormally shaped protein body structures. Results from these investigations reveal that the high protein digestibility sorghum mutation is likely different from that of *floury2*. *Floury2* was shown by Larkins group at University of Arizona to be caused by a gene mutation resulting in lack of cleavage of the signal peptide of some -zein storage protein. This can be visualized by an -zein protein band migrating to a higher molecular weight by SDS- polyacrylamide gel electrophoresis. The sorghum mutant did not show a similar band by electrophoresis. Studies in India showed high expression of the endoplasmic retention chaperonin, BiP, indicating a response to the unfolded structure of the protein bodies. The mutant sorghum kafirin storage protein also was found to have somewhat different solubility characteristics compared to normal sorghum grains. This may suggest either a mutation directly affecting one of the kafirin storage proteins or in a protein that assists the folding and interactions among the kafirins.

Chicken Digestibility and Growout Study

A collaborative study (see reference in publication list) was done with Dr. Robert Elkin, poultry nutritionist, to assess amino acid digestibilities and the value of the high protein digestibility sorghum on growth of broiler chickens (see publication reference below). A fairly floury mutant (P851171) was compared to its wild-type parent (P721N), a commercial hybrid (611Y), and maize. True amino acid digestibilities (TAAD) were substantially higher for the mutant and 611Y compared to either maize or P721N – mean TAAD values were 93, 93, 78, and 74%, respectively. These results confirmed the higher protein digestibility of the mutant. The commercial hybrid also had high protein digestibility and supports previous *in vitro* findings that some normal sorghum cultivars can have high protein digestibility. However, we also showed that digestibility of wild-type sorghum cultivars varied dramatically over years while the mutant remained high. Still, it must be concluded that not enough is known about variability in digestibility among wild-types.

For the growout study, mixed diets containing soy meal were prepared at optimum and suboptimum dietary crude protein levels. In this case, the high protein digestibility mutant sorghum slightly underperformed compared to the other grains in terms of feed/gain. There was, however, a confounding factor in the broiler study that made this comparison somewhat difficult. Because protein content of the other two sorghum samples was higher than the mutant and maize samples, cornstarch was added to the former diets at higher levels to make them isonitrogenous. The somewhat higher feed conversion of the normal sorghum cultivars may have been related to the added starch that is a ready source of energy for the bird. A future study should be conducted using sorghum with similar protein and starch contents which have been identified.

Economic Analysis

In a study (see reference in publication list) done by Purdue agricultural economist, Channing Arndt, and his student, the value of the high protein digestibility trait in sorghum was estimated relative to regular sorghum for market broilers. A least-cost feed mix linear programming model was used to optimize rations for starting and grown-for-market broilers in poultry production for three age categories: zero to three weeks, three to six weeks, and six to eight weeks. From amino acid digestibility parametric analysis, it was found that a premium for high protein digestibility sorghum increases essentially linearly with improvements in digestibility over the zero to 10 percent range. Concomitant increases in starch digestibility, if possible, would likely give this sorghum a real advantage for use in animal feed.

Sorghum Starch Digestibility

Factors Causing Low Starch Digestibility in Cooked Sorghum Porridges

The starch digestibility of cooked sorghum porridges is relatively low compared to other cereal flours such as maize (Thorne et al., 1983, American J. Clin. Nutr. 38:481). However, the digestibility for isolated sorghum starch is similar to that of maize in raw and in cooked forms. This implies that other flour components such as protein, anti-nutritional factors, dietary fiber, and lipid or complexation of starch with some of these components contribute to low sorghum starch digestibility. A nutritional study of children fed a sorghum-based diet showed that approximately 21% of calories consumed were recovered in feces compared to 13% for maize and 7% for rice (MacLean et al., 1981, J. Nutr. 111:1928). The overall objective of this research was to identify the fundamental factors causing lower starch digestibility in cooked sorghum flour compared to other cereals. Knowledge from this research will be used to optimize the use of sorghum as an energy source for human food.

Initial studies, reported last year, were conducted to determine the effect of some of the various flour components (antinutritional factors, fat and protein) on starch digestibility. Two sorghum cultivars, a normal (MR732) and high protein digestibility mutant (P851171) were used with maize and rice as the controls. Cooked sorghum porridges were significantly ($p<0.001$) less digestible than rice and maize. There were no significant differences in starch digestibility between the normal and the high protein digestibility sorghum cultivars before pepsin pretreatment. Decorticating and defatting significantly increased starch digestibility in all samples by a similar margin. Pepsin pretreatment resulted in significant increase in starch digestibility in all samples except for the normal sorghums. The highest increase was observed in the high protein digestibility cultivars (14 to 19%) followed by the maize control (8%) and rice (7%). These results show that non-starch flour components contribute to low starch digestibility and low protein digestibility seems to be the single largest contributor.

Subsequent studies in the past year were conducted using a wide range of samples as follows: high protein digestibility sorghum mutant lines - #222, P721Q, P851171 and #4; normal sorghums - MR732, P721N, #181, #30; controls – rice and maize. The samples were analyzed for protein and starch content and protein digestibility (Table 1). Similar results were obtained as in the initial study - no significant differences in starch digestibility among the sorghums and significant increase in starch digestibility in high protein digestibility sorghums after pepsin pretreatment (Figure 1). This was a consistent feature of all mutant lines. In conclusion, it has been shown that low starch digestibility in sorghum could be attributed to the low protein digestibility. This fact is further proven by the high increase in starch digestibility among the high protein digestibility mutants after protease pretreatment. A correlation of 0.97 was observed between starch digestibility and protein digestibility of sorghum cultivars when protease treatment preceded amylase digestion. High digestibility sorghums could have a useful impact in weaning foods and other foods where high availability of macronutrients is critical. Such sorghums could also find a place in diets of the marginally malnourished who do not meet UN-set requirements for protein and energy intake.

Starch Digestibility in Raw Grain

Studies have also begun on starch digestibility of sorghum with the aim of identifying ways to increase availability of grain starch for livestock and poultry. Results suggest

Table 1. Chemical composition, *in vitro* protein and starch digestibility of decorticated flours samples

Sample	Starch content (%)[a]	Protein content (%) [1]	Protein digestibility (%)	Starch digestibility (mg maltose)[2]
Rice	87.9	8.2	69.1	7.9
Maize	82.5	9.6	70.1	7.4
#222	74.7	11.7	75.5	6.5
P721Q	71.9	12.7	73.8	6.5
#4	74.6	10.9	75.7	6.6
P851171	74.9	10.2	73.0	6.5
MR732	83.5	9.0	53.8	6.2
P721N	77.6	10.7	22.6	6.3
#181	78.1	11.0	28.4	6.6
#30	75.1	13.3	27.3	6.2

[1] values reported on dry weight basis
[2] reducing sugar content values after 2 h digestion with -amylase

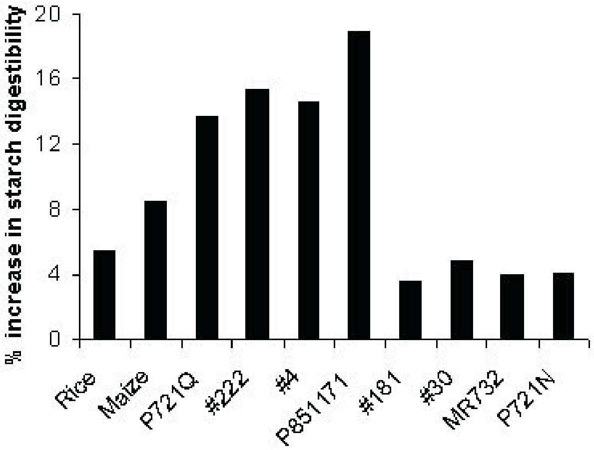

Figure 1. Percent increase in starch digestibility due to protease pretreatment.

Figure 2. Microwave popped sorghum.

that high protein digestibility sorghums, either the high digestibility mutant or normal cultivars with comparably high digestibility, also have more digestible starch. However, more work must be done to verify and better understand this relationship. In another study on this topic, the comparative rate of digestion of the two starch molecules, amylose and amylopectin, was performed. Quantification was done by measuring peak areas of size-exclusion chromatograms over a time-course digestion with -amylase. Amylopectin was found to digest at a significantly faster rate than amylose. Studies are in progress using other approaches to achieve higher starch digestibility in sorghum grain.

Microwave Popped Sorghum

A team composed of an undergraduate (Lindsey Kirleis) and graduate (Betty Bugusu, Agung Tandjung) students entered the product development competition at the American Association of Cereal Chemists annual meeting with a microwave popped sorghum product. Axtell's selections of popped sorghum (through assistance from Terry Lemming) were compared for popping volume, flake size, and number of unpopped kernels. An optimal line was chosen and preparation and conditions for a microwaveable popped sorghum bag were optimized to give maximum fill of bag. The team placed third in the national competition (Figure 2).

Networking Activities

Hamaker traveled to Manhattan, Kansas in July 2001 to present a talk to representatives of Japanese cereal processing companies at the Grain Sorghum Utilization Workshop. The meeting was sponsored by the US Grain Council and Kansas State University.

Publications and Presentations

Abstracts

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Han, X.Z., O.H. Campanella, and B.R. Hamaker. 2002. Characterization of the effect of starch damage on rheological properties of maize starch pastes. Institute of Food Technologists annual meeting, Anaheim, CA, June.

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Dissertations and Theses

Maladen, M. 2002. Characterization and carrying capacity of a soluble three-component complex. M.S.

Food and Nutritional Quality of Sorghum and Millet

Project TAM-226
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Summary

In Mali, an entrepreneur successfully produced N'Tenimissa, a white tan sorghum under identity preserved (IP) marketing procedures. The grain was used successfully by a large baking company to produce cookies.

When the government subsidized wheat flour, the entrepreneur found an alternative profitable market for decorticated white sorghum. The urban consumers liked the ready-to-cook product with substantial sales to expatriate Malians.

We hope these activities will expand. New more efficient white tan varieties are nearing release from the IER breeding program. The photosensitive types escape significant weathering/molding that adversely affects earlier insensitive white tans.

Value-enhanced white food sorghums developed in part by this project were promoted by the U.S. Grains Council in Japan and other countries for food processing. Value-enhanced white food sorghums have been used by the Japanese food industry to market snacks and several other products.

In Central America, white food sorghums are used in pan dulce, breads, cookies and other products as a substitute for wheat or maize flour.

Several mills are producing sorghum flour for niche markets. The operations are small but produce sorghum flour and other products that have been made into foods for Celiacs.

Special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products. The antioxidant level in brown sorghum bran is higher than that of blueberries.

New commercial sorghum hybrids with tan plant white pericarp color were released by commercial hybrid seed companies. Several parental sorghum lines released from our program are used in commercial food hybrids. ATX 635 hybrids have outstanding milling food properties.

Sorghum milling yields must be calculated on the basis of flour or grit yields adjusted to a common color value, i.e., an L of 67 for grits and 85 for flour where color attributes are important.

Antifungal proteins are related to grain mold resistance in sorghum. An improved faster assay was developed.

Near infrared equipment was calibrated and used for whole grain analysis of sorghums successfully. Calibrations for starch, protein and moisture for whole kernels of sorghum were developed.

A single kernel hardness tester was used successfully for hardness, kernel size and kernel weight. They are highly efficient methods for evaluation of grain quality. However, the hardness data was not significantly correlated with TADD hardness obtained by abrasive principles.

Two M.S. students completed their degree. Both joined the food industry.

Objectives, Production, and Utilization Constraints

Objectives

- Develop new food products from sorghum and millet using technology appropriate for use in less developed areas.

- Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum; seek ways of modifying its properties or improving methods of processing.

- Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.

- Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

The major constraint to development of profitable sorghum and millet foods remains the lack of a consistent supply of good quality grain at affordable prices. Until a source of Identity Preserved (IP), good quality grain can be produced, sorghum and millet products will be of inferior quality. Systems for marketing IP grains as value-added products for urban consumers are critically important.

Factors affecting food quality, processing properties, and nutritional value of sorghum and millet are critically important. If the grain cannot be processed and consumed for food or feed, then the agronomic and breeding research has been wasted. This project relates quality to measurable characteristics that can be used to select for sorghum and millet with acceptable traditional and industrial utilization attributes. It defines quality attributes and collaborates with breeders to incorporate desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptability that can generate income for farmers and entrepreneurs.

Grain molds significantly reduce the quality of sorghum for food and feeds. Information on the factors that affect mold damage of sorghum and methods to develop mold resistant sorghums is needed. This project addresses those critical issues.

Research Approach and Project Output

Sorghum and millet grains grown locally and from various areas of the world were analyzed for physical, chemical, structural, and processing properties. Various food and feed products were prepared to test the quality of the different grain samples. It became apparent early in our program that the acquisition of good quality grain for value added processing is absolutely essential to produce acceptable food products from sorghum and millet. That is why we have pushed hard for new improved varieties with good processing quality even if grain yield is not significantly increased. In most cases, systems to produce the new varieties and deliver the grain to processors is lacking and is difficult to put in place. Progress is happening but it is slow.

Significant Accomplishment

Applications of Technology in Mali

Work in Mali continues to demonstrate the value of new, white, tan plant sorghum varieties in food systems. During the past two years, progress to develop an effective IP production scheme to produce sorghum of good quality for processing into value-added flour and meal was demonstrated. The General Foods Company of Mali produced acceptable cookies containing the white food sorghum. However, the price of wheat flour decreased because of a Government decision to subsidize it, which caused the company to discontinue use of sorghum. This change meant the entrepreneur who obtained the IP food sorghum did not have a market for his grain. However, he was able to process the white food type sorghums into rice-like products that he sold for a profit. Thus, the concept has been proven by Malian personnel. New value enhanced food sorghums from the Malian sorghum breeding program will likely improve productivity and improve profitability. The key is to secure adequate production of the tan plant white sorghum varieties that can be IP and delivered to users at a profit for all participants along the value chain. The long-term sustainability is still to be determined.

Another positive is that farmers growing the white tans prefer the porridge made from these grains. This is similar to farmers in Honduras and El Salvador who prefer tortillas made from white tan plant sorghum varieties instead of the native Criollos, which have purple glumes. This project has interacted with the Malian program for more than 20 years. We hope that significantly faster progress will continue now that Malian business people are involved.

New Markets for Food Sorghums

Several extruded salty snacks and milled products based on IP U.S. white food sorghums continue to be sold by Japanese food companies (Figure 1). They are marketing flour,

Figure 1. Cookies containing white sorghum flour that are marketed in Japan.

meal, grits, and decorticated sorghum sold as a rice-like product. Korea and other countries are interested in using white food sorghums. Utilization of sorghum in these highly developed countries will help our efforts to convince food companies in other less developed areas that sorghum is a good food ingredient. Similar findings in Mali and other countries of West Africa demonstrate that sorghum of good quality is necessary for value added products. The same is true in Central America and Mexico.

Applications in Honduras and El Salvador

Our research on sorghum has been applied in Honduras and El Salvador. The variety Sureño, and others with white tan plant color are used in Central America for tortillas, rosquillos, and rosquettes. In El Salvador, sorghum flours from white tan plant varieties are used in small bakeries to produce pan dulce, muffins, bread, rosquettes, rosquillos and other variations of these products. There is significant interest in use of sorghum flour in blends and alone for baked products. There is a lack of milling equipment to secure flour although there appears to be sufficient production of food type sorghums. The ability to IP food sorghums for processing must be developed for consistent success. The opportunities exist to stimulate use of white food sorghums in Central America since a source of grain is available but technologies that can be used to decorticate sorghum and mill it into flour or meal are required.

Sorghum Phenols and Catechins as Antioxidants

Additional brown and black sorghum samples evaluated confirmed that brown high tannin sorghums have outstanding antioxidant activities. The ORAC values are comparable to blueberries and other fruits that are known to contain high levels of antioxidants. The antioxidants are concentrated in the pericarp and pigmented testa and can be easily processed into bran fractions Moreover, the bran is high in dietary fiber, phytates and natural brown or black pigments that impart attractive color to baked products such as cookies and multigrain breads. A healthy bread that contains modest levels of high tannin sorghums as a source of antioxidants is currently being sold.

Additional studies to produce highly nutritious multigrain breads and cookies are nearing completion along with a bread mix for bread machines. Black sorghum bran gave breads with appearance, texture, color, and specific volume (cm3/g) similar to commercial specialty or dark rye breads.

Ms. Linda Dykes, a Ph.D. student, has joined our efforts to characterize the phenols and tannins using HPLC and other techniques. Mr. J. Awika from Kenya continues his research on antioxidants in sorghum for his Ph.D.. His last year of study is supported by a Tom Slick Graduate fellowship which allowed us to leverage TAM-226 funds for other student activities.

Another student is nearing completion of her M.S. on the development of a bread mix containing brown or black sorghum bran with flax seed, gluten, and wheat flour. These breads have good flavor and color similar to variety breads.

Extrusion

Low-cost extrusion using friction produced excellent products from whole kernels of sorghum. More research will be done to demonstrate the utility of sorghums of various kinds in low-cost extrusion of snacks. These smaller extruders are used in areas where infra structure does not permit use of higher cost more sophisticated extruders and processes. Thus, the ability to produce snacks directly from whole clean grain would be a distinct advantage.

The evaluation of sorghum as an ingredient in extrusion of snacks and breakfast foods was initiated to compare its properties with corn and rice. This information is of interest to potential users of sorghum around the world. Rice produces extrudate with white, bland flavor and excellent crispness. Sorghum can be as effective but the price may be significantly reduced.

The goal of these experiments is to test the extrudate properties of sorghum directly against corn and rice ingredients. The white food sorghums have a bland flavor, light color and produce acceptable food products of various kinds. It is possible to produce expanded sorghums directly from whole ground undecorticated sorghum from white or brown grains. The color and flavor of the extrudates varied significantly. The brown sorghums after extrusion still had significant quantities of extractable antioxidants. Additional studies will demonstrate the use of extrusion to process the bran from brown and black sorghums into acceptable nutraceutical products.

Sorghum Starch, Malting and Brewing Studies

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to collaborate on sorghum research especially with students working on sorghum for brewing, industrial films and as a source of antioxidants. Dr. Serna has provided assistance to our project in El Salvador and Nicaragua by presenting a summary of his research activities on sorghum to Central American scientists at a planning workshop in Nicaragua.

Sorghum Flour in Specialty Products

Sorghum flour (SF) can be substituted for 100 % of the wheat flour in a variety of products that are used in gluten free diets for Celiacs who are intolerant of wheat and other cool weather cereals. Sorghum flour produces acceptable baked products with additives to substitute for its lack of gluten. Various prepared mixes, flours and other products containing sorghum have been introduced into specialty markets recently (Figure 2). These activities especially for special dietary requirements and ethnic foods are continuing to expand as more products are made available.

Figure 2. Commercial food products containing sorghum sold in the United States.

Central American Use of Sorghum

Ms. Herrera working with CENTA in El Salvador has conducted many trials in local bakeries showing that sorghum can be used effectively in baking of rosquetes, sweet breads and many other products as well. We have a program to work with her to assist in sorghum flour production from the improved white, tan plant food sorghums that are available in Salvador. This work along with the breeding program in El Salvador and Nicaragua will continue to improve sorghum quality for use in foods.

The lack of commercial production of sorghum flour by small operators is a major constraint to more widespread use of sorghum by small holders in the region. The need for IP food sorghum production and processing is critical. Bland flavor sorghum flour has an advantage over corn flour as a substitute for wheat flour. This affords an opportunity to utilize sorghum in popular food items. As we work to enhance utilization at the entrepreneur level, the combination of cereals and legumes to produce value-added foods is critically important.

The price of rice is such that locally grown sorghums could compete for markets in certain snacks, ready-to-eat breakfast cereals and composite flours for baking. In rural non-rice producing areas, a decorticated sorghum could serve as a cost effective substitute or diluent for rice in many households. Success could lead to significant economic activity.

Yield, Agronomics and Quality Attributes of Commercial White Tan Food Sorghum Hybrids

Samples of commercial sorghums exported from the Gulf Coast (11) and value-enhanced white food sorghums grown on farmers' fields (21) were analyzed for composition, physical, and milling properties. The white food grains had higher test weight, increased true density, reduced floaters, and significantly higher yields of decorticated grain than the commercial export sorghum samples (Table 1). The protein content of the food sorghums was significantly higher than that of the commercial sorghum samples. The white food type sorghums had significantly improved milling yields when adjusted to a common L value of 67. The red pericarp contributes significant color to the decorticated grain. The method we use to assess the relative color and decorticated grain yields provides a sensitive test to distinguish among sorghum cultivars. The effect of weathering and molds on decorticated grain yields is significant and white food types maturing or exposed to high humidity and heat after maturation have significantly reduced yields of acceptable products. The purple or red plant color sorghums are the most sensitive to these conditions.

Tan Plant Food Type Hybrid Performance and Quality Trials

Several new tan plant food hybrids were entered into uniform performance nurseries grown at five locations in Texas, two in Kansas and one in Nebraska. The tan plant hybrids were competitive with maturity comparable to traditional purple plant hybrids. The availability of short season tan plant hybrids is limited. More of them are required to encourage food sorghum production in drier, shorter season environments. Grain weathering and molds are limiting factors affecting food sorghum production. For example, in South Texas this year, the white food sorghums have been severely damaged by molds.

Grain samples from international food quality nurseries and hybrid trials are evaluated to monitor new materials in the pipeline and to encourage private seed companies to develop new improved value-enhanced hybrids. The grain industry in the U.S. is changing to a value-enhanced IP marketing system that fits into our long-term goal of improving sorghum quality for food and feeds.

Improved Methods of Analysis

Near infra-red equipment to analyze for protein, moisture and starch in whole grains was calibrated. The use of NIR to analyze for starch, protein and moisture is successful but continuous improvements in the calibrations are needed.

Table 1. Summary of Quality Data for Food and Commercial Sorghums Grown in 2001.

					Chemical composition (dry basis)					Grain yield		
Sample Type	Moisture (%)	Test Weight (lb/bu)	True Density (g/cm^3)	1,000 Kernel Wt. (g)	Protein (%)	Starch (%)	Oil (%)	Ash (%)	Fiber (%)	Dec.[1]y ield (%)	Dec.[2] (L=67) (%)	Hardness index
White FoodType												
Count	21	18	21	21	21	21	21	21	21	21	12	21
High	14.6	62.6	1.39	30.0	14.0	77.5	4.9	1.8	2.3	86.0	96.0	109.3
Low	7.4	56.5	1.34	18.3	8.7	71.4	2.5	1.1	1.6	71.3	77.0	60.9
Average	11.0	60.5	1.37	25.2	11.5	74.9	3.5	1.5	2.1	80.3	86.7	85.2
Std. Dev.	1.89	1.65	0.01	3.41	1.48	2.05	0.74	0.19	0.14	3.8	5.3	13.16
Commodity / Elevator												
Count	11	11	11	11	11	11	11	11	11	11	11	11
High	13.2	60.6	1.38	26.5	10	77.5	2.9	1.5	2.4	75.8	66.0	82.0
Low	12.7	59.7	1.37	24.7	9.3	76.5	2.5	1.4	1.9	72.5	52.0	6.2
360Average	12.9	60.2	1.37	25.6	9.5	77.0	2.7	1.5	2.0	74.0	58.5	78.6
Std. Dev.	0.19	0.31	—	0.54	0.27	0.35	0.14	0.02	0.14	1.0	4.8	1.60

[1] Decorticated Grain Yield (%) = 100 - % pericarp removed
[2] Decorticated Grain Yield (%) adjusted to comparable lightness values (L= 67)

A single kernel hardness characterization system used for wheat kernel hardness was modified slightly for sorghum kernel hardness, diameter, and moisture measurements. Unfortunately , the single kernel hardness value was not significantly correlated with the TADD decorticated grain yields of a set of 32 sorghum samples. This must be confirmed for a larger set of samples. At this time the abrasive milling procedure appears to be necessary especially if one wants to compare yields vs. color of the decorticated grain.

Grain Molds/Deterioration

Grain deterioration caused by molding is a major problem that significantly affects grain quality for sorghum utilization in most regions of the world. Grain molds and weathering reduce processing quality significantly and can totally destroy the value of the grain for humans. This often happens in the kharif sorghum crop in India and is common in the gulf coast areas of the U.S. and Mexico. In Mali, photo insensitive sorghum varieties are totally destroyed by the combination of head bugs followed by molds, which render the kernels soft, floury and easily pulverized. The grain cannot be decorticated to mill into flour. Thus, farmers grow photosensitive types.

Many factors affect the molding of sorghum and none of them in themselves account for tolerance. The kernel structure, especially endosperm hardness, pericarp surface wax covering, presence of a pigmented testa, phenolic compounds, plant height, glume characteristics, antifungal proteins, and many unknown factors affect grain mold tolerance. Our research over the years has identified some of them but with the exclusion of the high-tannin sorghums no factor appears dominant.

Role of AFP in Minimizing Grain Molding of Sorghum

An improvement in the analysis procedure was implemented last fall (2001) for the sorghum samples collected in 2001. Threshed, hand-cleaned, and Udy-mill ground sorghum samples were mixed for 1 hr with the extraction buffer with agitation, followed by centrifugation, and the supernatant was collected. The Western blotting procedure was replaced with a "dot" blotting procedure. Protein extracts were directly loaded into nitrocellulose membrane using a 96-well, dot-blotting apparatus. The membranes with the proteins were then blocked, incubated with the antibodies and then visualized as in the Western blotting procedure. With this procedure, the gel formation, electrophoresis, gel handling, and protein transfer steps were skipped. Hence, analyses are now completed more efficiently and about three times more samples can be analyzed in the same time period. The results of the traditional Western and dot blotting procedures do not yield the same values but the trends and cultivars identified as being responsive and resistant are similar.

The sorghum growing environments in 2000 and 2001 did not attain mold rating greater than "2" or low incidence of deterioration at 50 days after anthesis. This indicates these sorghums were grown in environments that were not very mold conducive. The sorghum growing environments in 2002 already has more precipitation during and after anthesis and during caryopsis development than the previous two years combined. Raul Rodriguez previously demonstrated that in mold-conducive environments, grain-mold resistant sorghums respond with more AFP; and in non-mold-conducive environments this correlation was not significant. Samples are now being collected to verify this relationship in about 55 elite sorghum lines and 25 commercial hybrids. Significant molding has occurred this crop year.

We have made progress in a collaborative study with Dr. Louis Prom, USDA plant pathologist, concerning the virulence of *Fusarium thapsinum*, *Curularia lunata,* and their mixture on eight sorghums varying in resistance to grain molding. A manuscript was submitted for publication: "Response of eight sorghum cultivars inoculated with *Fusarium thapsinum*, *Curvularia lunata*, and a mixture of the two fungi" by Louis K. Prom, Ralph Waniska, Kollo Abdourhamane Issoufou, and William Rooney.

The interactions of the principal grain molding fungi, the sorghum genotype, and the environment on the level of grain mold severity and seed germination were determined. Grain mold is considered a complex disease associated with several genera of fungi. The synergistic interaction of fungi did not markedly increase the levels of grain molding, except on 98LB650 in 2000. The effect of F. thapsinum and C. lunata in combination was similar to the individual pathogen that produced the highest grain molding on many cultivars in this study. Therefore, in screening for resistance against grain molding, inoculation with a mixture may not be as effective as inoculating with the individual fungi that are the most prevalent. Also, fungal treatments significantly reduced seed germination more than it increased seed deterioration as measured by the threshed grain mold rating.

Networking Activities

Southern Africa

Several graduate students are conducting research on aspects of sorghum utilization with Professor Taylor, Food Science Department, University of Pretoria. Ms. Leda Hugo, Mozambique, is a Ph.D. student at University of Pretoria working on the effect of malting sorghum on its use in composite breads. She is a professor at University of Eduardo Mondlane University and completed her M.S. at Texas A&M University. Lloyd Rooney serves on her Ph.D. committee. She will complete her Ph.D. in August 2002.

Ms. S. Yetneberk from Ethiopia has started her Ph.D. program and L. Rooney is a co-director of her committee. Her project is related to determination of factors affecting the quality of injera from sorghum cultivars present in Ethiopia.

Graduate students in the Food Science Department at the University of Pretoria are from many other African countries. Many participate in the Regional Master of Science program which consists of joint programs between CSIR and the University of Pretoria. Thus, INTSORMIL interaction with the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL can provide significant assistance to the region by involvement in these programs.

Mr. J. Awika from Kenya completed his Ph.D. written and oral preliminary examinations. He is working on nutraceuticals from sorghums. He received several scholarships from national and local sources due to his outstanding academic performance. He was partially supported by INTSORMIL but was awarded a competitive Tom Slick Research Fellowship from TAMU which supports his last year of Ph.D. research.

Mr. Hoffman of Namibia conferred with INTSORMIL project leaders regarding pearl millet research and development activities. We provided support for conferences with commercial milling equipment companies in our area.

Honduras, Salvador, Mexico and South America

Rene Clara, Sorghum Breeder, El Salvador and sorghum breeders from Nicaragua spent time in the cereal quality lab. Dr. L. Rooney, traveled to Managua, Nicaragua to develop collaborative research plans. The information obtained in Japan applies quite well to the situation in Salvador and elsewhere in Central America. A small Central American food company has initiated use of modest amounts of sorghum in their extruded snacks as the result of participation in our snack foods short course.

L.W. Rooney has long term cooperative projects with Dr. S. Serna-Saldivar, Professor and Head, Food Science, Instituto Tecnologico y de Estudios Superiores de Monterrey (ITESM), Monterrey, Mexico, to evaluate the usefulness of new improved food sorghum hybrids in wet and dry milling and as adjuncts in brewing. His Ph.D. and subsequent post doctorate experience in our laboratory was partially funded from INTSORMIL.

We currently have three graduate students from Mexico partially funded on TAM-226. We are able to leverage our INTSORMIL funds by using additional research funds from private industry and other agencies to conduct joint research activities. The practical short course on Snack Foods provides opportunities to conduct proprietary research projects for participants. These short courses generate funds that are used to partially support graduate students.

Mr. Bueso, Honduras, is nearing completion of his PhD and is supported this last year by a Tom Slick Graduate Fellowship from Texas A&M University. His research is on tortillas and related products.

Mali

Dr. A. Toure presented a Faculty of Food Science special seminar that summarized current progress in utilization and breeding research in Mali where significant progress continues to develop identity preserved production and use of the new white plant photosensitive sorghum varieties. I have not visited Mali recently but the work we initiated continues and is on the verge of being successful and is supported by other agencies including ROCARS and ICRISAT. Thus our long term efforts accompanied by many setbacks are now being pursued actively in Mali. It is clear that many scientists and others understand that acquisition of good quality sorghum and millet grains for processing is necessary to produce profitable, competitive food products. This has been demonstrated in Niger and many other places where poor quality grain produced unacceptable products that consumers will not buy.

North America

Several papers were presented at the annual American Association of Cereal Chemists Conference, Charlotte, N. Carolina. L.W. Rooney presented sorghum quality/utilization discussions to the Texas Sorghum Producers Board Members and panels and the U.S. Grains Council sponsored visitors and reported on value-added conferences in Japan.

Lloyd Rooney was a key speaker at a KSU Feed and Food Grains short course on Value Added Food Sorghum which had more than 25 participants from Asia, Mexico and Central America.

Lloyd Rooney completed a two year research project which was funded (100K+) by the Texas Advanced Technology Research program to evaluate special sorghums for antioxidant potential and use in nutraceuticals. Sorghum bran fractions contained from 20-400+ ORAC units compared to 80-200+ ORAC units for blueberries which are considered excellent sources of antioxidants

Visitors and collaborators from Southern Africa, Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador, Korea, Japan, Venezuela, Colombia, and China were presented information.

Our laboratory conducts an annual short course on practical snack foods production for private industry in which sorghum utilization is part of the program. A book on Snack Food Processing co-edited by Lloyd Rooney contains information on food sorghum. Participants from all over the world enrolled in the short course including several from Central America and Mexico. This short course produces a profit which is used to partially support research activities, another example of leveraging of resources.

Sorghum Market Development Activities

The U.S. Grains Council has market development activities to capitalize on value-enhanced sorghums for use in value-added products in Japan, Taiwan, Mexico, Central and South America. Our research activities on development of food type sorghums, milling properties, composite flours, tortillas, snacks, and other prototype food products was presented at U.S. Grain Council sponsored value-enhanced market development work shops in the United States and Japan.

Training, Education and Human Resource Development

At the Monterrey Institute of Technology, our collaboration with Dr. Serna-Saldivar, Head, Food Science Department, ITESM, Monterey, Mexico has lead to completion of six Master of Science degrees. These young scientists have positions in the Mexican food industry which transfers the technology directly to industry. Dr. Serna-Saldivar participated in the Central American Regional planning workshop in Managua, Nicaragua this spring. He summarized his work on sorghum utilization.

Three graduate students from Mexico and one from Honduras currently work on INTSORMIL related research in our laboratory, with partial financial support while several others are supported from non INTSORMIL funds. Inflation has significantly reduced the number of graduate students that can be supported. J. Awika from Kenya is a Ph. D. candidate. We have assisted in training two students from Africa who are enrolled at U of Pretoria working under Professor John Taylor at the University of Pretoria.

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Host Country Program Enhancement

Central America

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Description of Collaborative Program

Institutions

Active INTSORMIL collaboration in Central America is occuring primarily among the following institutions: Centro Nacional de Technología de Agricopecuaria y Forestal (CENTA), El Salvador; Instituto Nicaragüense de Tecnología Agropecuaria (INTA) ,Nicaragua; Universidad Nacional Agraria (UNA), Nicaragua; Universidad Nacional Autónoma de Nicaragua (UNAN), Nicaragua; Escuela Agrícola Panamericana (EAP), Honduras; Kansas State University, Mississippi State University, Texas A & M University; and the University of Nebraska.

Organization and Management

In 1999, INTSORMIL shifted program emphasis in Central America to El Salvador and Nicaragua. Scientists from collaborating institutions met and developed a research plan for the 2000 -2001 years with collaborative projects in plant breeding, utilization, plant protection (entomology and plant pathology), and agronomy. On February 27-28, 2002 scientists met to present two-year research results and develop priorities for collaborative research for 2002-2006.

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America Regional Program budget, which was $105,000 during the past year.The four collaborative research projects (plant breeding, utilization, plant protection, and agronomy) were budgeted $16,000 each, with the balance maintained at the INTSORMIL Management Entity to cover regional expenses. These regional expenses included short-term training for three scientists in plant breeding, expenses associated with the Central America Sorghum Research Conference, equipment purchases and administrative travel.

Collaboration

INTSORMIL's Central America program has supported informal collaboration with many non-governmental organizations mainly in validation of sorghum varieties, and formal collaboration with national extension services, and it has served as a catalyst for Central American grain sorghum research and technology transfer. In addition, René Clará Valencia coordinated the regional grain sorghum yield trials conducted by the PCCMCA, and grain sorghum germplasm was shared with watershed projects of the Centro Internacional de Agricultura Tropical (CIAT) at Yorito, Honduras and San Dionisio, Nicaragua. During the past year, a collaborative relationship was developed with ANPROSOR, the Nicaraguan grain sorghum producers association, which has assisted in identifying research priorities and is collaborating with a number of research studies in 2002.

Sorghum Production/Utilization Constraints

Grain sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to grain sorghum in 2000 was 252,544 ha^{-1} with an average grain yield of 1.5 Mg ha^{-1} (FAO, 2001). During the last decade sorghum grain yield in Central America increased due to improved technology (including improved cultivars and hybrids, herbicides, insecticides, planting date, minimum tillage, seed treatments and fertilizer) available to producers.

Small-scale Central American farmers are burdened with low productivity and limited land resources. Intercropping provides a means to increase total productivity per unit land area and reduce the risk of dependence on one crop. The dominant cropping system is maize intercropped with maicillos criollos (called millón in Nicaragua). These tropical grain sorghums are three to four meters tall, drought tolerant, and photoperiod sensitive. The grain is used as human food and a feed grain for livestock, and the stover is used for livestock forage. Although maicillo criollos produce low yields, they are planted on approximately 67%, of the grain sorghum area in Central America.

The limited grain yield response of traditional maicillo criollo varieties to management practices is a primary constraint to increased production. Soil and water conservation, improved production practices and soil fertility management, and increased genetic potential of cultivars is essential to obtain economical yield increases. To date, increased grain sorghum production, yield and area are due primarily to utilization of improved cultivars (hybrids and varieties).

Alternative uses for sorghum grain need to be developed to encourage sustainable economic growth in semi-arid areas in Central America. White grain, tan-plant colored grain sorghum cultivars are well adapted to Central American human food and livestock feed systems. Innovative processing systems, like extrusion and flaking, are needed to increase starch digestibility and maximize net energy intake for livestock feed. A lack of milling equipment for production of grain sorghum flour limits adoption of the use of grain sorghum flour for baked products. Human consumption needs to be promoted, especially in tortilla related products, extruded snacks and flour substitution through use of superior grain-quality sorghum cultivars. Use of grain sorghum cultivars for forage, or dual use for both grain and forage are important to small producers.

Research Accomplishments and Planning

Sorghum Research Reporting and Planning Workshop

The workshop was held on February 27 - 28, 2002 and attended by 36 participants sponsored by INTSORMIL, 5 sponsored by INTA, and several administrators from INTA, UNA and ANPROSOR. The first day focused on presentation of experimental results from the past two years, and was brought to a close by presentations by Francisco Vargas (ANPROSOR) on sorghum producer priorities, Pedro Pablo Orosco (CIAT) on verification research and technology adoption by small farmers, and the keynote presentation on the potential future uses of sorghum in Central America by Dr. Sergio Serna Saldivar, Monterrey, Mexico. Efforts are being made to publish certain reports in a special issue of the journal "La Calera."

The second day focus was developing multi-disciplinary team efforts for work plan development, after starting with a presentation about community-based extension programs. The following programmatic changes were developed based on production/ processing themes identified during the conference.

Plant Breeding

(1) **Future direction** should focus on variety development in El Salvador and hybrid development in Nicaragua, although degree training will be required for implementation.

(2) **Lodging**. An increased effort on lodging issues will be implemented recognizing the need for increased collabration with agronomists, plant pathologists and entomologists.

(3) **Grain quality**. Efforts will be continued to produce white kernel, tan plant type grain sorghum cultivars. Increase efforts for tan glumes, thin pericarp, larger round kernel, high density and high test weight will be implemented. Increased collaboration with plant pathologists on grain mold/weathering resistance. Increased educational efforts with private industry and extension services in the value of white sorghum for livestock feed. Increased collaboration with food scientists is needed to develop quick food quality tests for evaluation of advanced breeding materials.

(4) **Forage**. Continue efforts with stay green, and brown midrib/juicy midrib traits. Increased collaboration with plant pathologists for resistance to leaf diseases. Ruminant animal science projects do not exist in INTSORMIL, but increased collaboration with this discipline is needed.

(5) **Insects and Diseases**. Increased collaboration with entomology and plant pathology to identify priorities for research. Workshop presentations suggest an Anthracnose priority in Nicaragua, rust priority in El Salvador, grain mold priority for food and feed uses, and the langosta insect complex is a problem in the entire region.

(6) **On-Farm Testing**. Need to develop collaborative efforts with plant pathologists, entomologists and agronomists.

(7) **Drought Tolerance.** Continue recognizing interactions with management practices.

(8) **Special Needs**. Regional breeding programs need to generate more of their own material and evaluate segregating material, since there are unique adaption reactions in Central America. Institutional development and training of young plant breeding scientists is urgently needed.

Agronomy

(1)**Orientation**. Although some station research is justified, but the emphasis will shift to on-farm research.

(2) **Collaboration**. Efforts need to have broader collaboration with universities, national programs (including extension services), private companies and NGOs.

(3) **Research Focus**. One of the priority research needs is nutrient management, especially for N and P. This should focus on evaluating N rate recommendations on-farm, and collaborating with plant breeders to identify nutrient use efficient cultivars. These efforts should include evaluation for grain physical quality and nutritive value. Weed control was identified as an important problem, but it was felt that adequate resources would not be available to address both fertilizer use efficiency and weed control issues in the near future.

(4) **Soil Degradation**. Interest was expressed to pursue collaboration with CIAT in their watershed project to evaluate the effect of different sorghum-based production systems on soil erosion. This interest is enhanced by a new French led project with CIAT and INTA to focus on upland rice and grain sorghum.

Plant Protection

(1) **Production constraints**. Interdisciplinary efforts to study grain sorghum production on farms with the intent to identify production constraints.

(2) **Economic thresholds**. Producers expressed need to develop scouting procedures and economic thresholds, and train agronomists, producers and chemical salesmen on their use.

(3) **Plant resistance**. Collaborative research should increase for host-plant resistance to anthracnose in Nicaragua, and rust in El Salvador.

Grain Utilization

(1) **Sorghum flour**. Increased research should be conducted on the use of decorticated grain to increase shelf life.

(2) **Grain quality**. Continue to collaborate with plant breeders to improve grain quality of new cultivars and genetic materials, including resistance to grain mold/weathering damage.

(3) **Scientific capacity**. There is a huge need in El Salvador and Nicaragua to improve scientific capacity through graduate education. This is evident given that Fidelia Herrera is the only food scientist working with grain sorghum in El Salvador or Nicaragua. Interest was expressed in trying to develop collaboration with a university in El Salvador.

(4) **Animal use**. Emphasized the importance of effectively incorporating Dr. Joe Hancock into the regional effects, especially in Nicaragua where sorghum is widely used for animal feed.

Plant Breeding

Research Methods

The plant breeding programs in both El Salvador and Nicaragua are striving to identify adapted grain sorghum lines with good agronomic and utilization characteristics for development either as photoperiod-sensitive or insensitive varieties for grain production or dual use as grain and forage. Photoperiod-sensitive lines may also serve as parents for hybrids. Once potentially superior lines are identified, then preliminary yield trials are conducted followed by on-farm verification trials and ultimate release. The breeding programs are constantly evaluating new sources of germplasm identified in the region, from INTSORMIL breeding programs in the United States, and from ICRISAT. Each year, grain sorghum hybrid tests have been conducted in three to seven countries in Central America. In 2001, these studies were conducted in the Dominican Republic, El Salvador, Guatemala, and Nicaragua with 16 hybrids/varieties from the private companies Cristiani Burkard (Guatemala), SEMINACA (Venezuela), Monsanto, and from the El Salvador national program (CENTA) are being evaluated.

Research Results

Regional trials were conducted for photoperiod insensitive varieities, and hybrids in the Domincan Republic, El Salvador and Nicaragua. The combined analysis indicated that the photoperiod insensitive variety ICSV-LM 89503 produced higher yield than the local check. The white grain, tan plant hybrids ATX 629 × 86EO361 and ATX 623 96CA635 were the highest yielding with over 7.4 Mg ha^{-1}. The PCCMCA hybrid trial was conducted at eight locations, with the cultivars CBX-8016-2 and CBX-8016-1 producing the highest average yield of over 6.4 Mg ha^{-1} with the local check cultivar having an average yield of 5.1 Mg ha^{-1} (Table 1).

Research in Nicaragua focused on evaluation of photoperiod-sensitive and insensitive varieties. The photoperiod-sensitive variety EIME 113 appears to be a promising with high yield (4.7 Mg ha^{-1}), desirable plant, panicle and grain properties. Other promising early generation lines were identified for further testing in 2002. An evaluation of 30 hybrids from El Salvador and 160 hybrids from Texas were evaluated, and based upon the performance of the 10 best hybrids identified the inbred lines ATX-623, ARG 34-A, ATX-629, 96CA635, BTX-635 and 98BRON-125 as promising for hybrid production for Nicaragua production conditions. Germplasm from Texas A & M University Drought Line Test (81 Advanced Lines) Midge Line Test (70 Advanced Lines), and Grain Weathering (Mold) Test (40 Advanced Lines) were evaluated for the second year, and useful material will be incorporated into the Nicaraguan breeding program.

In El Salvador, photoperiod-sensitive lines were evaluated in relay intercropping with maize, and photoperiod insensitive varieties and hybrids were evaluated. The photoperiod-sensitive varieties 85-SCP-805, ES-790, EIME-119, 86-EO-226, Pre-EIME-112 and Punta de Lanza were well suited to relay intercrop production with maize producing 4.3 to 5.9 Mg ha^{-1} yield without reducing maize yield, but Punta de Lanza was tall and susceptible to lodging. Three superior white grain, tan plant hybrids [ATX-623*86-EO-361, 8.1 Mg ha^{-1}; 34-A*86-EO-361, 7.2 Mg/ha; and ARG 34-A*96EON-328, 6.7 Mg ha^{-1}] were identified. The red grain hybrids produced lower yields than the white grain hybrids, but ARG 34-A*ICSR-LM 92502 and ATX-623*ACSR LM-92502 were promising with 6.4 Mg ha^{-1} yields. The photoperiod insensitive variety ICSV LM-90538 appeared very promising with a yield of 7.9 Mg

Table 1. Cultivar evaluation in the PCCMCA Regional trial, results averaged over eight locations in four countries.

Entry	Yield (Mg ha)	Height (cm)	Disease Rating (1 = excellent; 5 = poor)
CBX-8016-2	6.7 a	168	2.2
CBX-8016-1	6.6 ab	176	2.2
HIMECA 101	6.5 abc	166	2.7
MTC-1197	6.3 abcd	150	2.4
MTC-7439	6.2 abcd	162	2.6
D-66	6.1 abcd	154	2.5
MTC-7379	6.1 abcd	156	1.9
MTC-1177	6.1 abcd	164	2.3
CB-2006	6.0 abcd	151	2.6
MTC-7389	6.0 abcd	157	2.2
HIMECA 404	5.7 abcd	179	2.2
ESHG-2001	5.4 bcd	136	2.2
ESHB-2	5.2 cde	129	2.7
CB-8966 (TC)	5.2 cde	155	2.7
Local Check	5.1 e	182	2.0
ESHG-1	4.3 e	131	2.7
Mean	5.8	157	2.4
C.V. (%)	14	6	24

ha^{-1} which was 1.6 Mg ha^{-1} higher than the next best variety.

Considerable interest is present for pearl millet as a forage crop in El Salvador and Nicaragua, and as a potential grain crop in the driest production areas of Nicaragua. Twenty-four forage pearl millet cultivars from INTSORMIL Project ARS-204 were evaluated as a green chop forage source, and 10 of these cultivars produced good yields of high quality forage in this system.

Entomology and Plant Pathology Research

Research Methods

Farmer surveys and evaluation of the All Disease and Insect Nursery (ADIN) were used in El Salvador and Nicaragua in 2000 and 2001 to identify the pests more commonly occurring in grain sorghum fields to help guide future research. M.S. thesis research on sorghum midge was conducted in Nicaragua. This studied midge seasonal occurrence *(Stenodipolosis sorghicola)*, oviposition behavior on specific hosts and management strategies including planting date, sorghum variety and insecticide efficacy. In El Salvador, insecticide studies on fall armyworm were conducted.

Research Results

Producer surveys and evaluation of ADIN indicated that the most prevalent sorghum disease in Nicaragua was anthracnose and in El Salvador it was rust *(Puccinia* species), and the most prevalent insect pests were fall armyworm *(Spodoptera frugiperda*) and sorghum midge. INTSORMIL Project MSU-205 has conducted research on fall armyworm for over a decade and on sorghum midge during the past four years. Future research will emphasize collaborative, multidisciplinary, multiinstitutional, on-farm pest management tactics and strategies in collaboration with ANPROSOR, National Grain Sorghum Producers Association. Entomology research will continue to focus on fall armyworm and midge, while the pathology research will shift emphasis to anthracnose and rust.

In El Salvador, insecticide evaluations indicated that the chiten inhibitor insecticides Lufenuron and Teflubenzuron provided the best control of fall armyworm, with intermediate control with Lorsban, and low efficacy for several biological insecticides. Water volume had little effect on efficacy of Lorsban, while repeat applications increased control. Sorghum plants damaged during early growth were capable of compensation for fall armyworm damage, indicating that crop growth stage should be considered in making insecticide recommendations. Additional research is needed to define recommendations for fall armyworm control at different growth stages of sorghum.

Grain Utilization (Quality) Research

Research Methods

The Central America program has historically concentrated on improving the grain yield and processing characteristics of sorghum for use in tortillas and related products with research conducted at the Escuela Agricultura Panamericano (EAP) in Honduras. In recent years the research has broadened to include grain sorghum flour substitution in yeast and sweet breads in El Salvador. This research has included market surveys, and research on specific grain quality/food utilization issues usually with undergraduate students at EAP, or graduate students at Texas A & M University or the Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico.

Research Results

Research in El Salvador during the past 20 years has developed the technology for incorporating sorghum flour from white, food-grade sorghum cultivars for use in French and sweet bread for urban areas, and use of 100% sorghum flour for sweet bread, cold drinks (horchatas, refrescos), and hot drinks (atoles); and the use of popped sorghum (alboroto). During the past year the focus has been on technology transfer of this technology in urban areas. This included 22 training sessions with 124 members of the Asociacíon Salvadoreña de Panifacadores (ASPAN) in urban areas, who are substituting 5 to 10% sorghum flour in French bread and 25 to 40% sorghum flour in sweet breads. In addition, one private company who produces snack food (golosinas) is interested in using sorghum flour. There is need to develop "identity preserved" strategies to assure consistent flour quality, and to obtain equipment to decorticate sorghum and to mill the quality flour required. Strategies to address these issues and assist with micro-enterprise development will be a priority in the coming year.

Agronomy Research

Research Methods

Agronomic research was conducted in 2000 and 2001 to evaluate nitrogen use efficiency of grain sorghum photoperiod-sensitive and insensitive genotypes and to determine optimal nitrogen fertilizer rate recommendations. Four to six grain sorghum varieties were grown at sites in El Salvador and in Nicaragua with four nitrogen fertilizer rates. Flowering date, plant height, grain and stover yield, and grain and stover nitrogen concentration data were collected. Fertilizer and utilization nitrogen use efficiencies were calculated from these data.

Research Results

Only small differences in fertilizer and utilization nitrogen use efficiency was found among the photoperiod insensitive varieties tests, thus it was concluded that screening of a broad base of germplasm was required to identify high nitrogen use efficient genotypes. (UNL-213, Table 4). This research is being initiated in the coming year. The photoperiod-sensitive variety 85-SCP-805 produced high grain yield and grain nitrogen use efficiency, while ES-790 had very high fertilizer nitrogen use efficiency.

Nitrogen fertilizer application increased grain yield quadratically at each location with the highest nitrogen rate not maximizing grain yield. The impressive yield increases obtained from nitrogen application are being tested on-farm during the coming year.

Mutual Research Benefits

Many production constraints are similar between Central America and the U.S. including drought, diseases, and insects. U.S. based scientists can provide germplasm that could at least partially alleviate the effect of some of these constraints. The maicillo criollos are a unique type of grain sorghum and can potentially contribute useful food quality traits to U.S. germplasm, and several lines are presently in the Texas A&M University /USDA-ARS Sorghum Conversion Program. Germplasm exchange will contribute to development of novel genetic combinations with multiple stress resistance, wide adaptation, and improved food quality. Entomology and plant pathology research includes pests that affect grain sorghum both in Central America and in the U.S., such as sorghum midge and ergot.

Institution Building

Equipment and Other Support

INTSORMIL has provided pass-through funding and supplies for pathology laboratories in El Salvador and Nicaragua, notably repair of a Zeiss microscope at UNA resulting in a potential savings of $10,000. Books, reprints and other written materials were provided in several disciplines. A computer was provided to INTA, along with pollinating bags to plant breeding.

Training and Education

Mr. Javier Bueso (Honduras), Assistant Professor, EAP , is pursuing a Ph.D degree in the Grain Quality Lab at Texas A&M University. Johnson Zeledon (Nicaragua) is pursuing a Ph.D. degree at Mississippi State University with dissertation research on grain sorghum insect pest management in Nicaragua and the United States.

Drs. Claflin (KSU-210B) and Pitre (MSU-205) conducted a five-day sorghum plant protection workshop in Managua, Nicaragua, 10 - 14 June, 2002 for 36 agricultural professionals from Nicaragua and two from El Salvador. Short-term training for grain sorghum plant pathologist Yanet Gutierrez (UNA) was provided at Kansas State University, and for plant breeders René Clará and Hector Deras (CENTA) and Rafael Obando (INTA) at Texas A&M University.

Networking

Institutions/Organizations

Collaboration among CENTA, INTA and UNA have improved greatly during the past three years, and an increased number of countries participated in PCCMCA trials this year. In El Salvador, increased collaboration with the NGOs MAG/AVES, FUNDPROCOOP, PRODAP, and FUNDESYRAM primarily with validation testing of sorghum varieties to be released. In Nicaragua, increased collaboration with the CIAT Hillside Project at San Dionisio has been forged. National programs have strong linkages to private seed companies, and are developing closer ties with feed and food utilization companies. Noteworthy is the close working ties with the Asociacíon Salvadoreña de Panifacadores (ASPAN) in El Salvador. Improved networking with INTSORMIL universities and Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico is desired through graduate education and collaborative research efforts.

Travel

INTSORMIL sponsored the Central America Sorghum Research and Planning Conference, 27 - 28 February, 2002 with 40 participants.

Dr. Henry Pitre traveled to El Salvador and Nicaragua to direct graduate student research and assist with collaborative research. He was a presenter in the Sorghum Pest Management Work Shop, 10 - 14 June, 2002.

René Clará represented INTSORMIL at the PCCMCA meeting in the Dominican Republic in April, 2002. He represented the Central America Regional Program at the joint Technical Committee/Host Regional Coordinator Meeting in Lincoln, NE in April, 2002. He traveled to Nicaragua in June, 2002 to assist in coordinating research activities in Nicaragua and El Salvador.

Dr. Larry Claflin visited INTSORMIL scientists conducting collaborative research in El Salvador and Nicaragua in Dec., 2001 and February, 2002. He was a presenter in the Sorghum Pest Management Work Shop, 10 - 14 June, 2002.

Drs. Joe Hancock, Gary Peterson, Darrell Rosenow, Lloyd Rooney, Bill Rooney and Thomas Crawford participated in the Central America Sorghum Research and Planning Conference, 27 - 28 February, 2002.

Dr. Stephen Mason, Regional Coordinator, made trips to El Salvador and Nicaragua in Nov. 2001 and Feb. 2002.

Horn of Africa

Gebisa Ejeta
Purdue University

Program Coordinators

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Peter Esele, Uganda country Coordinator, Serere Agricultural and Animal Production Research Institute, Serere, P.O., Soroti, Uganda

Collaborative Program

INTSORMIL/Horn of Africa is an initiative to regionalize our collaborative research efforts in Eastern Africa. Before the start of the current regional effort, INTSORMIL had a productive collaborative program with the Agricultural Research Corporation (ARC) in Sudan. This collaboration has resulted in an array of technical developments that have impacted on sorghum agriculture in Sudan. Sudanese scientists have been trained in INTSORMIL institutions. U.S. scientists have traveled extensively in Sudan and worked alongside their Sudanese counterparts. Joint workshops and conferences were organized and attended. Results of joint research efforts have been published and distributed widely. Extensive raw and improved germplasm have been identified, assembled, and catalogued for the benefit of U.S. and Sudanese agriculture.

Under the Horn of Africa initiative, memoranda of agreements have been signed with NARS in Ethiopia, Eritrea, Kenya, and Uganda. With these MOA, INTSORMIL now has collaborative relationships with five countries in the Horn of Africa region. A two-tier program has been under development in the Horn of Africa. With each national program, we have initiated a traditional collaborative program between a NARS scientist and a U.S. principal investigator(s) on a topic of common concern and interest with at least one disciplinary project identified in each country. A scope of work is jointly developed and submitted for review and approval by the NARS country coordinator, NARS research director and the Horn of Africa program coordinator before becoming the INTSORMIL/Host Country workplan. Each workplan has its own funding. Funds are forwarded directly from Purdue University, and are then disbursed in-country to each collaborating scientist to carry out the research project. With limited funds available to the INTSORMIL/Horn of Africa, it has not been possible to initiate a full range of collaborative projects with each of the NARS in the region. Instead, the intent has been to establish a full complement of collaborative partnerships with the Institute of Agricultural Research in Ethiopia and to use this program as a hub from which to network with the other member countries of the Horn. A line item for networking has been built into the budget of the INTSORMIL/Horn of Africa program to catalyze exchange of information and ideas among member NARS and INTSORMIL scientists. A major initiative that has been under consideration is the identification of major regional constraints upon which considerable research may have been undertaken by one or more of the NARS in the region. There has been great interest among scientists in the region to identify such research projects and undertake regional evaluation and verification with the hope of generating technologies that could have regional application. We continue to have dialogue on the feasibility of implementing such a regional initiative. Once agreed upon, collaborative research projects among NARS in the region will be developed, in consultancy with appropriate INTSORMIL scientists, on a priority research agenda of regional importance. Inputs from concerned scientists in the region will be solicited in developing the research agenda as well as in refining the research protocol on a timely basis. Collaborative scientists will be encouraged to meet regularly (preferably once a year) to exchange ideas and to sharpen the focus of the regional research agenda.

Annual field/laboratory touring workshops will be organized alternately at a site in one of the host countries in the region. Participation in the tour will be based on interest and the topic of the workshop for that year. These tours will provide INTSORMIL PIs opportunities for interaction with many scientists in the region. Scientists from the region will also have an opportunity to pick up useful germplasm, research techniques, or potentially transferable technologies that they may come across during these tours.

Opportunities for collaboration with other organizations such as ASARECA, ICRISAT/East Africa, World Vision International, Sasakawa Global 2000, and the IPM CRSP have been good and there are initiatives under development with each of these organizations. Discussions have also been underway to determine possibilities of buy-ins from USAID Missions in the various countries in the Horn of Africa. A major agreement was developed between INTSORMIL, USAID/REDSO/East, and the Inter-Governmental Agency for Development (IGAD) with funds allocated through the Greater Horn of Africa Program. Through this initiative INTSORMIL spearheaded a study on availability and use of technologies that alleviate problems associated with dryland agriculture. This comprehensive study is expected to provide direction for future agricultural research and transfer of technologies for drought prone environments of the Horn of Africa.

Research Disciplines and Collaborators

Ethiopia

Agronomy – Kidane Georgis, EARO; Jerry Maranville, INTSORMIL.

Striga Management – Gebremedhin Woldewahid, EARO, Wondemu Bayu, MOA; Gebisa Ejeta, INTSORMIL.

Entomology – Tsedeke Abate, EARO; Henry Pitre, INTSORMIL.

Agricultural Economics -Yeshi Chiche, EARO; John Sanders, INTSORMIL.

Sorghum Utilization – Senait Yetneberk, Aberra Debelo, EARO; Lloyd Rooney, Bruce Hamaker and Gebisa Ejeta, INTSORMIL.

Research Extension – Beyene Seboka, Aberra Deressa, EARO; Gebisa Ejeta, INTSORMIL.

Pathology – Girma Tegegne, IAR; Larry Claflin, INTSORMIL.

Kenya

Sorghum Breeding – C. K. Kamau, KARI; Gebisa Ejeta, INTSORMIL.

Food Quality – Betty Bugusu, KARI; Bruce Hamaker, INTSORMIL.

Striga – C. Mburu, Kari; Gebisa Ejeta, INTSORMIL

Uganda

Sorghum and Millet Pathology – Peter Esele, NARO; Gebisa Ejeta, INTSORMIL.

Striga Management – Joseph Oryokot, NARO; Gebisa Ejeta, INTSORMIL.

Eritrea

Sorghum Breeding – Tesfamichael Abraha, DARE; Gebisa Ejeta, INTSORMIL, Eritrea – Neguse Abraha, DARHRD,

Entomology – Asmelash Woldai, DARE; Henry Pitre, INTSORMIL.

Striga Management – Asmelash Woldai, DARE; Gebisa Ejeta, INTSORMIL.

Sorghum/Millet Constraints Researched

Sorghum and millet are important crops in all of the countries in the Horn of Africa, ranking first or second in cultivated area among the major cereal crops of the region (Table 1). Sudan and Ethiopia are the indisputable centers of origin for sorghum and are major centers of genetic diversity for both crops. In addition, a wealth of improved sorghum and millet germplasm has been made available in both of these countries as a result of association with INTSORMIL and ICRISAT. Collaborative research between Sudan and INTSORMIL has also resulted in research and production technologies that can be shared by other members of the Horn of Africa.

According to the sorghum and millet scientists in the Horn of Africa region, “the major sorghum and millet pro-

Table 1. Sorghum and Millet Production.

	Sorghum			Millet		
Countries	Area 1000 ha	Yield Kg ha^{-1}	Production 1000 mts	Area 1000 ha	Yield Kg ha^{-1}	Production 1000 mts
Eritrea	60	842	51	15	546	8
Ethiopia	890	1236	100	280	1000	280
Kenya	120	745	90	85	682	58
Sudan	4684	785	2386	1150	192	221
Uganda	255	1498	382	407	1602	652

Table 2. Production constraints of sorghum and millet across eastern Africa countries.

	Eritrea	Ethiopia	Kenya	Sudan	Uganda
Varietal Development	X	X		X	X
Striga	X	X	X	X	X
Crop Protection					
Pest	X	X	X	X	X
Diseases	X	X	X	X	X
Drought	X	X	X	X	X
Production	X	X	X	X	X
Technology Transfer	X	X	X	X	X
Training – Long-term	X	X	X		X
- Short-term	X	X	X	X	X
Socio-economics				X	
Utilization	X	X	X		X
Information Exchange				X	X
Germplasm Introduction	X	X	X		X
Soil/Water Conservation	X		X		
Seed Production & Marketing	X	X	X	X	X

duction and utilization constraints are generally common to all countries (Table 2).

These constraints include lack of improved germplasm, drought, *Striga*, insects and diseases (anthracnose, leaf blight, grain molds, smuts, ergot in sorghum, blast, downy mildew, and ergot in pearl millet). Other problems in the region include lack of adoption of new production and utilization technologies by farmers, soil/water management techniques, as well as the infrastructure and technology for production and marketing of seeds and other essential inputs.

Agronomic research on soil and water conservation techniques has not been extensively evaluated in any of the countries in the region. Lack of moisture and soil nutrients and poor husbandry are primary constraints of sorghum and millet production. Breeding efforts currently in use to incorporate drought tolerance traits to genotypes with high yield potential are limited by lack of a field screening procedure and lack of knowledge of sources of appropriate germplasm with useful traits. The lack of absolute definition of good food quality parameters and good screening methods for food quality to some extent also limit the utilization of high yielding sorghum and millet varieties. Very little research has also gone in developing germplasm with resistance to the major insect pests and diseases. *Striga*, a major parasitic weed of sorghum and millet, constitutes a major constraint to the production of these crops. There is very little sorghum and millet germplasm with resistance to *Striga* and the mechanisms that render resistance to *Striga* are not well understood. Knowledge about inheritance of many of these traits is also lacking. In many of these areas, the crop/bush fallow system of production has traditionally been used to provide enough nutrients and possibly some moisture for a period of crop years (5-10 years fallow/2-4 years cropping). In some areas, other crops are often grown in an intercropping system with millet and sorghum to maximize production. Over the last 2-3 decades, rainfall in the Horn of Africa region has declined, thus reducing the soil recovery rate during fallow. Fallow periods have also decreased due to higher human and animal pressure on plant cover, resulting in further reduction of sorghum and millet yields in the region. Research on all of these aspects is needed to improve sorghum and millet production and utilization in the Horn of Africa.

Research Progress

Ethiopia

Breeding Sorghum hybrids
(Zenbaba Gutema)

The superior performance of hybrid sorghums under stress environments, demonstrated by several sorghum worker, led to the initiation of a modest sorghum hybrid program in Ethiopia. Over the last 20 years several hundred hybrids have been developed and evaluated for their yield potential across moisture stressed lowland sites. Some of these hybrids were uniquely adapted to many of the lowland, moisture stress environments of the country combining early maturity with very high grain yields. Unfortunately, however, seeds and records of these hybrids and their parental material were lost during the political unrest in the country in 1991.

The fact that these experimental hybrids demonstrated stable performance across environmental extremes as compared to recommended open-pollinated varieties, encouraged us to restart this work in order to increase and stabilize food production in the more hostile environments. Further, experience in other African countries, though limited, offers great promise for continuing hybrid sorghum research in our local environments in Ethiopia. Our sorghum hybrid development activities received a great boost with the establishment of a collaborative research with INTSORMIL. Highlights of these activities are briefly presented below.

Evaluation of A, B and R Lines and Experimental Hybrids

In collaboration with Purdue University we have been evaluating a number of A, B and R lines. In addition several test crosses and experimental hybrids have been evaluated.

The total numbers of such introductions and selections are indicated in Table 3. Each year a number of crosses are made at our off-season station, Melka-Werer. The hybrids are evaluated at various stages at Melkassa; Miesso and Kobo research stations, which are, located dry lowland areas. Hybrids that showed good agronomic performance over the standard check with higher yields are subjected to yield trials in the areas as much as we can cover. Yield, grain quality, panicle exertion, drought tolerance and lodging resistance are the most important characteristics in selecting the hybrids. Tables 4 and 5 present hybrids developed by the program in collaboration with Purdue University. In these tables we can see that most of these hybrids performed better under dry conditions of Ethiopia as compared to the standard open-pollinated varieties. Experimental hybrids also flowered earlier than the open pollinated cultivars used as checks.

In addition to *Striga* nurseries, A, B and R lines and experimental hybrids several genotypes with important traits such as *Striga* resistance, drought tolerance and lodging resistance also have been introduced and evaluated. Again numbers of introductions and selections are given in Table 3.

Eritrea

Millet Breeding
(Negusse Abraha)

Pearl millet (*Pennistum glaucum*) is grown mainly for grain in the tropical and sub-tropical areas of Africa and in the Indian sub-continent. It is an indispensable food for millions inhabiting the semi-arid and arid tropics and is more important in the diet of the poor. In Africa, 70% of the pearl millet produced is grown in western Africa. In Eritrea, pearl millet is grown on total area of over 45,000 hectares and is second in importance among the cereals following sorghum. It is widely used as a grain crop in western and eastern lowlands of the country whereas its use as forage is limited. Under the situation of subsistence farming that exists in pearl millet producing areas of Africa, including Eritrea, grain yields are limited by the poor inherent soil fertility and water holding capacity of the soil and traditional management practices, including limited use of fertilizers and tillage. Further, limitations are imposed by drought, disease (downy mildew), insect pests and low genetic yield potential of traditional landraces .

Research activities on pearl millet have been carried out in Shambiko Research Station. Primary introduction of germplasm for evaluation in Eritrea has been obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Screening of these introductions in subsequent years has led to the release of two cultivars as best varieties (ICMV 221, ICMV 91450) for wide distribution. In the year 1999, ICMV 221 was multiplied and distributed in Zoba Gash Barka and in the year 2000, it was distributed in Zoba Anseba. However, the climate and soil condition of Shambiko Research Station was not a typical pearl millet growing area. Therefore, it was recommended to start research activities in Zoba Anseba , Sub-Zoba Hagaz in new research site. Hagaz Research Station is located at an altitude of 850m above sea level. with minimum and maximum temperatures of 15 c and 45 c respectively. The average rainfall ranges from 300 – 400 mm/annum. The new site has a typical arid and semi-arid climatic conditions which is conducive for pearl millet research work.

At Hagaz, research activities started in 2000 as an off-season program. Germplasm for this program was mainly from the local gene bank (DARHRD) and from the breeding program at ICRISAT. Crossing was done between five selected landraces and five introduced materials. In addition, selfing was done on the best landraces. The result of this activity was continued in the rainy-season of 2000. This section discusses on the breeding activities done during off-season and rainy-season of year 2000.

Experimental material that included 10 local landraces and one released variety as a check was evaluated using a randomized complete block design with three replications.. They were planted with spacing of 4m x 0.75m x 4 rows. Observations were recorded on the central 2 rows of each plots for the following characters:

Table 3. Germplasm introductions from Purdue University and evaluated in Ethiopia from 1996 to 1999.

Types of introduction	1996		1997		1998		1999		Total	
	Intro. *	Adva**	Intro.	Adva.	Intro.	Adva.	Intro.	Adva.	Intro.	Adva.
A & B lines	40	5	158	11	-	-	9	9	207	25
R-lines	-	-	-	-	-	-	223	20	223	20
Test crosses	164	28	-	-	-	-	-	-	164	28
Experimental hybrids	-	-	-	-	54	30	419	218	473	248
Lines with various genetic merits	-	-	400	42	-	-	-	-	400	42
Lowland drought escape materials	-	-	-	-	79	27	-	-	79	27
High potential lines	-	-	-	-	-	-	25	4	25	4
Total	204	33	558	53	133	57	676	247	1571	390

* Introduced
**Advanced

Table 4. Mean grain yield (Q/ha), days to 50% flowering and plant height (cm) of 12 varieties included in Elite Sorghum Hybrid Trial One (ESHT-1) at Melkassa (MS) and Mieso (MI) in 2000 cropping season.

		Grain yield			Days to flowering			Plant height	
Entry #	Identification mean	MS	MI	Mean	MS	MI	Mean	MS	MI
8	P-9518A × 90MW 534456	43	50	67	66	67	190	185	188
6	P-9513A × MR-747*180	52	42	47	69	68	69	180	179
2	M-90950A × MR-747*187	43	50	47	74	71	73	168	205
9	P-9518A × KCTENT #17 DTN 184	49	42	46	68	67	68	185	183
5	P-9513A × 90MW5344 190	45	45	45	68	68	68	186	193
7	P-9518A × 91MK 7013 176	45	37	41	67	66	67	170	182
4	P-9513A × MR-747 167	45	32	39	70	70	70	160	173
1	M-90950A × 91MK 7013*179	38	36	37	74	75	75	166	192
3	P-9513A × P-89006 166	42	29	36	72	69	71	164	167
10	M-90950A × P-46-1 134	32	33	33	67	67	67	116	151
11	Meko 158	31	32	32	66	64	65	160	156
12	Local check 216	21	35	28	86	90	88	188	244
	Mean	42	38		71	70		169	183
	CV%	17	14		3	3		7	7
	LSD (0.05)	10	7		3	3		16	18

* Non-Purdue female parents

Table 5. Mean grain yield (Q/ha), days to 50% flowering and plant height (cm) of 14 varieties included in Elite Sorghum Hybrid Trial Two (ESHT-2) at Melkassa (MS) and Mieso (MI) in 2000 cropping season.

		Grain yield			Days to flowering			Plant height	
Entry #	Identification mean	MS	MI	Mean	MS	MI	Mean	MS	MI
1	P-9501A × ICSR-14 162	60	46	53	65	68	67	174	147
7	P-9534A × KCTENT #17 DTN 171	61	44	53	71	70	71	181	160
2	P-9501A × ICSR-16 164	63	40	52	69	70	70	174	153
5	P-9534A × ICSR-16 168	65	39	52	68	71	70	173	162
8	ICSA-34 × ICSR-14*159	61	40	51	70	70	70	166	152
10	ICSA-34 × ICSR-10*153	50	38	44	68	70	69	156	149
9	ICSA-34 × ICSR-16*150	51	37	44	68	70	69	155	145
6	P-9534a × 82(PLYT-2#5) × 81ESIP 46 161	55	31	43	69	71	70	173	149
3	P-9501A × PGRC/E #222880 182	69	17	43	67	77	72	196	167
14	Local Check 205	47	29	38	86	90	88	215	194
12	ICSA-10 × SK-82-022*176	51	22	37	69	72	71	189	162
4	P-9534A × ICSV-89106 168	42	26	34	73	73	73	179	156
13	Meko 148	34	33	34	66	67	67	166	129
11	ICSA-34 × MR-747 140	38	28	33	72	68	70	138	142
	Mean	53	34		70	72		174	15
	CV%	16	18		2	4		9	15
	LSD (0.05)	12	9		2	4		23	32

* Non-Purdue female parents

days to 75% flowering, plant height, plant count, head count, panicle count, panicle yield and grain yield. To maintain soil fertility, 100 kg ha^{-2} DAP before planting and 100 kg ha^{-2} urea 3 weeks after planting were applied. Thinning and transplanting were done 2 weeks after planting. During the growing period of the crop, 260 mm was recorded and 6 times was supplemented by irrigation. It was cultivated once and hand weeded twice.

The analysis of variance for plant height showed highly significant difference ($P < 0.001$) for days to 75% flowering indicating that plants did not reach 75% flowering date at the same time. In addition, there was significant difference ($P = 0.047$) for plant height. However, there was no significant difference ($P = 0.291$) for the character grain yield showing that there was no significant difference between the landraces for grain yield.

Mean comparison among the ten land races were made (Table 6). When days to 75% flowering was considered, the earliest variety was ICMV 221 (check) and the latest was Bultug Keren. This landrace got acceptable range of grain yield and high levels of downy mildew susceptibility that will require the introgression of resistance from introduced sources. When the grain yield, agronomic score and downy mildew % is considered, Tosho and Zibedi performed better than others and they attain grain yield of 19% and 4% above the mean grain yield respectively. Though there is significant difference between the land races for plant height, all have acceptable range of plant height except one landrace, Gudamay which is short (152 cm). Tokroray, a bristle landrace got the least grain yield and became the most susceptible to downy mildew disease, probably this requires improvement by crossing with resistance and high yielding exotic variety.

Table 6. Preliminary Result of Landrace Millet Varieties Evaluated in Eritrea.

S.N.	Landraces	Flower Day (75%)	Plant ht	Grain yld T/ha	Downy mildew (%)	Agro.score Rank
1	Bultug mebred	49	179	4.33	31.3	1
2	Bultug keren	57	212	5.42	29.4	2
3	Gudmay	48	152	3.74	24.8	4
aspalpha4	Shileti	49	185	3.97	41.7	5
5	Tokroray	49	189	2.88	47.7	1
6	Tosho	47	169	4.84	21.3	2
7	Zibedi	47	174	4.20	14.0	3
8	Kunama berta	49	182	3.64	14.7	4
9	Bicha kunama	49	164	3.75	35.6	3
10	Bultug barka	53	171	3.90	28.2	5
11	ICMV 221	45	172	3.87	1.9	1+
	Mean	49	177	4.05		
	CV %	2.0	8.2	1.97		
	S.e.	1.11	14.5	0.88		
	LSD	2.6	29.2	1.61		
	F- value	***	*	NS		

In addition to the landraces, 52 exotic varieties with three local checks were also evaluated. The experimental design used was RCBD with three replications. The spacing was 4m x 0.75m x 4 rows. Observation was done on two central rows. Traits were considered were days to 75% flowering, plant height, plant count, head count, head yield, and grain yield. Fertility was maintained by adding 100 kg ha^{-2} DAP at the time of planting and 100 kg ha^{-2} urea after three weeks. Thinning and transplanting were also done three weeks after planting. The field was cultivated once and hand weeded twice. During the growing period of the crop, 161.6 mm of rainfall was recorded and it was supplemented seven times by irrigation.

In the analysis of variance for grain yield, there was highly significant ($P < 0.001$) difference between the varieties showing that there is varietal difference in performance. Moreover, there is highly significant ($P < 0.001$) difference for the traits of days to 75% flowering and plant height. This indicated that there is genotype variation in flowering time and attained different plant heights.

The main objective of this trial was to select some promising varieties for future breeding work. Among the 52 experimental varieties, 15 were selected for advanced yield trail (Table 7). Within these varieties, there is no significant difference (3.60 – 4.56 t) for grain yield when they are compared using LSD (1.19) and all have good resistance to downy mildew disease. The plant height attained is at acceptable range (151 – 215 cm) and days to 75% flowering can also be said early for all the 15 varieties (38 – 46 days).

Kenya

Sorghum Breeding
(C.K. Kamau and C. Mburu)

Sorghum (Sorghum bicolor) is an important crop in the semi-arid areas of Kenya. The Sorghum and Millet Program was initiated to increase food security and reduce poverty. To come up with new varieties of Sorghum, yield testing of elite material is conducted in Preliminary Yield Trial, Advanced Yield Trial (AYT), Sorghum National Performance Trial (SNPT) and Sorghum Malt Quality Yield Trial (MQSYT). The elite material are from diverse sources but mainly the Kenya Agricultural Research Institute's (KARI), sorghum breeding program at National Dryland Farming Research Center (NDFRC), Katumani and International Crops Research Institute for Semi Arid Tropics, (ICRISAT) and International Sorghums and Millets (INTSORMI) group of universities. Program activities are targeted at the semi-arid areas where sorghum has a comparative advantage over other cereals. Other researches aimed at enhancing the position of sorghum in the national economy are also conducted.

During the long 2000 and short rains 2000-2001 several experimental trials were undertaken in the KARI/INTSORMIL Sorghum and Millet Collaborative Program: -

The trials comprised of 31 sorghum selection replicated two times in randomized complete block design. Plot size was 3 rows 4 meters long planted at 75 cm apart. Seeds were drilled in the row and thinned to a spacing of 20 cm between plants. The middle one rows was harvested for analysis and evaluation. Selections were assessed for grain yield, stand count, Days to 50% flower, head exertion and plant height.

Based on yield at Katumani eight of the selections were dropped and the seven top yielders were promoted to Advanced Yield Trial (AYT) the rest of the selections were retained in this stage for further testing.

In this yield trial 21 entries were tested in a Completely Randomized Block Design (CRBD) with three replicates during the short rains 2000. Plot size was 3 rows 4 meters long planted at 75 cm apart. Seeds were drilled in the row and thinned to a spacing of 20 cm between plants. The middle one row was harvested for analysis and evaluation. Entries were assessed for grain yield, days to 50% flower and plant height. The results of the top nine performers are shown.

Table 7. Preliminary Result of Exotic Pearl Millet Varieties Evaluated in Eritrea.

S.N.	Variety	Days to flowering (75%)	Plant ht	Grain yield (t/ha)
1	ICMP 89410	42	177	3.92
2	ICMP 93508	45	179	4.17
3	ICMP 95490	41	175	4.56
4	ICMP 97774	41	175	3.75
5	ICMP 98107	42	163	4.11
6	EERC CO	38	160	3.16
7	ICMR 312	42	156	3.99
8	IAC ISC YCP1	43	190	4.22
9	IAC ISC TCP3	40	157	3.84
10	IAC ISC TCP4	44	176	3.85
11	IAC ISC TCP6	46	182	3.72
12	IPC MBJ TCP CO	44	151	3.60
13	POLCOL TCP1	44	164	4.11
14	AfPop 88	46	215	4.13
15	SenPop 88	42	183	3.98
Zibedi (check)		43	165	2.69
B/Keren (check)		47	165	2.69
ICMV 221 (check)		38	149	3.47
Mean		42	162	3.30
CV%		1.1	0.8	0.72
S.e.		0.45	1.23	0.24
LSD		1.62	19.90	1.19
F-value		***	***	***

In the 2000 long and short rain seasons, sorghum yield trials were conducted at Katumani. The trials comprised of 16 varieties replicated four times in randomized complete block design. Plot size was 4 rows 4 meters long planted at 75 cm apart. Seeds were drilled in the row and thinned to a spacing of 20 cm between plants. Only the middle two rows were harvested for analysis and evaluation. Entries were assessed for grain yield, stand count, days to 50% flower head exertion and plant height. The effects of the seasons were also assessed. Data was analyzed by analysis of variance (ANOVA) using General Linear Models (GLM) procedure of SAS (SAS Institute, 1994) and means were separated using Least Significant Differences (LSD).

The two seasons (2000 LR and 200SR) were significantly different in respect of stand (stand establishment) days to flower (maturity), Exertion, plant height, and Grain yield ($p<0.01$). The short rain season was much better than the long rain season.

The varieties were different in stand count, exertion, plant height ($P<0.01$) but not in days to flower and grain yield. The C.V. were generally high, this could be explained by the fact that the seasons were extremes, one very wet and the other very dry. Of the sixteen varieties tested 8 entries performed better than the check variety. There was significant site by entry interaction for stand, exertion, plant height but grain yield and day to flower. The results are shown below.

In another trial 9 varieties introduced for high malting quality were tested for yield beside traits like stand establishment, day to flower (earliness) head exertion and plant height. There were significant differences between season in stand establishment, day to flower exertion plant height and grain yield ($p<0.001$). The short rain season was much better than the long rains season. The results are shown in table 4.

The varieties were different in stand establishment; exertion, plant height and grain yield but not in days to flower. There was significant season by variety interaction stand, head exertion plant height and grain yield but not for day to flower.

Elite lines/Breeders Seed Increase

In this activity Breeders Seed was produced for KARI-Mtama-I, ICSV III, IS76, Serena and Seredo.

In the same activity seed was increased for elite lines in NPT, AYT, PYT and malt quality sorghum trial to back up on-farm research and other activities of the breeding program.

The aim of this activity is to sensitize visitor on the progress of the Sorghum and Millet Program. Varieties about to enter on-farm testing were demonstrated.

In this activity a chief baraza was convene to talk about dryland crops farming in Kimutwa Machakos prior to on-set of rains 2000 short rains season. At the end farmers interested in growing sorghum were asked to volunteer. 31 farmers who volunteer were each given 2kg of KARI-Mtama-1, ICSV 111 or Seredo sorghum varieties. They were trained on necessary management to achieve the highest yields possible.

The season has been very successful. The farmers' response has been that they will certainly grow sorghum in coming seasons. Harvest of threshed grain on farmers' field range from 107 to 430 kg. Land planted on the variety is variable depending farmer efficiency in use of the seed and management.

A *Striga* resistance sorghum nursery trial comprising of twenty-five introductions from Purdue University (U.S.)

were tested in Alupe sub-center, of the Regional Research Center Kakamega in the Lake Victoria region of Kenya. The *Striga* resistance nursery was planted, during the 1999 short rains and 2000 long rains season. Farmers' local variety was included as a check. The trial was planted in RCBD with 4 replications. Each entry was planted in 3 row plots, each row being 5 m long. Plant and row spacing were 15 cm and 75 cm respectively. The recommended fertilizer rate in the region (20 kg N and 20 kg P2 05 per hectare) was applied. Weeding was done twice before the emergence of *Striga* weed. Thereafter, other weeds were hand-pulled leaving only *Striga*.

Data collected include days to flowering, plant height, yield, and *Striga* count among others. Harvesting was done at physiological maturity, and seed kept for planting during the succeeding seasons. The seasons were significantly different in *Striga* count, day to flower, plant height, midge damage and yield $P<0.01$ but not for stand count. The results are shown in Table 8.

Entries had significant differences in stand per plot, days to flower (DFLW), midge damage (score), *Striga* count (*Striga*), plant height (plant ht (cm), and grain yield (t/ha) ($P <0.01$). There was significant entry (variety) by season interaction for grain yield only. The results are tabulated in Table 9.

Institution Building

Field supplies, laboratory materials and two computers were purchased for the Eritrea program. This past year, sor-

Table 8. Mean Seasonal Performance of 26 Sorghum Varieties in the *Striga* Resistance Sorghum Nursery During Short Rains 1999 and Long Rains 2000 Seasons.

	Trait					
Seasons	Stand	DFLW	Midge	Striga	Plant ht (cm)	Yield (t/ha)
Short Rains 1999	72.7	63.5	3.4	24.5	126.1	2.3
Long Rains 2000	69.5	70.3	5.9	49.4	115.8	1.1
Mean	71.1	66.9	4.6	36.9	120.9	1.7
LSD (0.05)	3.6	2.4	0.3	12.8	4.1	0.2
SD	14.8	10.5	1.9	59.7	18.3	1.4

Table 9. Mean Performance of 26 Sorghum Varieties in the *Striga* Resistance Sorghum During Short Rains 1999 and Long Rains 2000 Seasons.

	Trait					
Entry	Stand	Dflw	Midge	Striga	Plant ht(cm)	Yield(t/ha
8551	62.4	71.4	4.8	18.6	106.1	1.3
8552	72.8	64.1	4.8	23.5	108.2	0.8
8553	69.8	72.5	5.3	18.9	119.8	0.9
8554	62.3	73.6	4.9	20.8	128.8	1.7
8555	72.4	74.0	4.3	8.5	117.4	1.3
8556	77.7	72.9	4.5	36.5	122.0	2.1
8557	71.8	60.8	4.3	16.9	131.0	2.1
8558	60.4	63.1	5.4	29.6	98.8	1.3
8559	70.8	61.9	5.4	11.0	121.5	1.4
8560	72.9	62.6	4.3	44.0	129.6	2.2
8563	65.8	71.8	4.8	47.0	125.0	1.7
8564	78.3	67.1	4.1	15.4	119.0	2.1
8565	73.3	61.8	5.1	23.2	119.6	1.5
8566	65.4	65.6	5.1	17.1	124.0	1.3
8568	75.1	61.9	5.4	3.6	123.3	1.3
8571	73.0	59.4	4.8	19.1	123.0	1.8
8572	79.5	69.4	3.9	129.0	108.4	1.5
8573	43.1	77.1	5.3	133.4	111.8	1.1
8574	72.3	69.5	4.5	18.6	128.1	1.8
8575	76.8	67.8	4.1	87.3	135.3	4.2
8576	78.9	70.6	5.1	35.6	112.8	1.2
8577	71.8	66.9	5.8	43.0	133.5	1.0
8578	79.0	58.3	2.8	59.5	131.8	4.2
8579	64.5	71.1	4.8	9.3	105.8	1.1
8580	76.6	57.8	5.0	15.0	114.0	0.8
8581	82.1	66.5	2.6	77.3	145.5	3.4
Mean	71.1	66.9	4.6	37.7	120.9	1.7
LSD (0.05)	12.9	8.6	1.2	46.3	14.7	0.7
SD	14.9	10.5	1.9	59.7	18.3	1.4

ghum pollinating bags and an Almaco low-profile thresher (Model LPR-UMB-D) were shipped to Ethiopia.

15 – 19 July 2001 – Dr. Aberra Deressa, EARO/Nazret Research Director, and Dr. Hamis Saadan, Senior Agricultural Research Officer, Ministry of Agriculture/Tanzania, visited Purdue University to discuss current research in Ethiopia and discuss the feasibility of a new collaborative research program in Tanzania.

This travel was supported by the HOA program in conjunction with their participation in the Global Consortium of Higher Education and Research for Agriculture (GCHERA) held in San Francisco from 12 to 14 July 2001.

9 - 22 December 2001 – Dr. Ejeta traveled to Ethiopia to initiate a new sorghum project with EARO as well as work with the research group involved in INTSORMIL activities. He also worked with the EARO Committee which is assisting the Management Entity in organizing the All-PI meetings.

10 – 31 May 2002 - Dr. Gebisa Ejeta traveled to Ethiopia to help set up and facilitate organization of the research to be conducted by Luke Snyder, graduate student, in the implementation of a pilot project on integrated *Striga* management that includes water conservation, Nitrogen fertilization, and *Striga* resistant varieties.

During that time, he also traveled to Tanzania to meet with Dr. Saadan and Ministry of Agriculture staff regarding collaborative research. Negotiations are pending until the MOU is signed by the Ministry.

West Africa/Western Region (Mali, Ghana, Senegal)

Darrell T. Rosenow
Texas A&M University

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Dr. John Sanders, Economist, Purdue University, West Lafayettte, IN

Collaborative Program

Program Structure

The INTSORMIL collaborative program in Mali is a large multidisciplinary research program. The program centers around Malian scientists and each Malian scientist develops research plans cooperatively with a U.S. counterpart which provides for effective research planning, communication, and coordination. Each year INTSORMIL collaborators travel to Mali as appropriate to observe field trials, consult, review progress and plan future activities with Malian scientists. Occasionally, IER scientists also travel to the U.S. for research review, planning, and coordination. The planned project activities then become part of the annual Amendment to the MOA between INTSORMIL and IER.

The program includes all aspects of sorghum/millet improvement with major emphasis on breeding or germplasm enhancement, utilization and quality, nutrient use efficiency, soil management, insect pests, disease control strategies, and *Striga* control.

A new thrust to the program previously centered in Mali began in 2000-2001 with the initiation of collaborative INTSORMIL research in Ghana and Senegal. A MOU between INTSORMIL and ISRA (Institute of Agricultural Research) in Senegal was signed in early 2001. An existing MOU with SARI (Savanna Agricultural Research Institute) in Ghana which involved agronomic research between Dr. S.S. Buah and Dr. J.W. Maranville was utilized to include the new collaborative efforts in Ghana.

Collaborative research was initiated in the 2001 crop season in both countries in breeding, pathology, entomology, and *Striga*, and also in agronomy in Ghana, continuing some of the research initiated in collaboration with Dr. J. Maranville. Breeding, disease, insect, drought, and *Striga* trials were developed collaboratively with Malian and U.S. INTSORMIL scientists and grown in Ghana and Senegal as well as in Mali. Some of these were also offered to scientists in Niger, Burkina Faso, and Nigeria, and scientists there requested seed of specific nurseries according to their interests and needs. Also, an elite sorghum germplasm nursery from worldwide sources was sent to Ghana and Senegal to broaden the genetic base of their breeding program. The mechanism for developing collaborative research plans is evolving as new INTSORMIL PIs initiate their programs, and PIs are able to travel to these new countries. The PI Conference in Ethiopia in November, 2002 will serve as the initial broad based planning conference for collaborative research efforts among Mali and the new countries as well as with the Eastern Region (Niger, Nigeria, and Burkina Faso) scientists.

Other Collaboration

Collaboration involving germplasm exchange, workshops, monitoring tours, and specific research projects continued with the regional networks ROCARS (WACSRN), and ROCAFREMI as well as with ICRISAT at Samanko outside Bamako, Mali. There also was cooperation with NGOs such as World Vision, Winrock, and CMDT in evaluation of potential new cultivars as well as with the Soil Management CRSP and the SYNGENTA Foundation.

Financial Input

The USAID Mission has in the past provided significant financial support to IER research program through the SPARC Project which ended in June 1997. In addition to the Malian Government, the Ciba Giegy Foundation (Syngenta) and World Bank support the IER research program.

Sorghum/Millet Constraints Researched

Plant Production Constraints

The yield level and stability in sorghum and millet production is of major importance in all the countries. Drought is a serious constraint to production over much of the area. Diseases, insect infestations and *Striga* significantly affect both sorghum and millet production. Head bugs and associated grain molds adversely affect sorghum yield and grain quality of sorghum. Anthracnose is a very severe sorghum disease in the more humid areas and long smut is severe in the drier regions. Sooty stripe can be a severe leaf disease problem. *Striga* is a major constraint for both sorghum and millet. Downey mildew is a serious problem on pearl millet.

Land Production Constraints

Low soil fertility combined with the low yield and unstable yields of local cultivars affect sorghum and millet production. Major soil related constraints to production are phosphorus and nitrogen deficiency, and water stress.

Technological and Socioeconomic Constraints

There is a lack of farm credit policy which would encourage adoption of improved sorghum and millet new cultivars. In addition, the prices of these two cereals are low and unstable. New shelf-stable foods, industrial sorghum and millet based products, and enhanced use for animal feed are needed to encourage production.

Research Methods

The collaborative program in the Western Region of West Africa emphasizes research in breeding (germplasm enhancement), entomology, pathology, agronomy (soil, water, fertility relationships), weed science (*Striga*), cereal technology (quality and utilization), marketing, and technology transfer. An effort to develop new food products from sorghum and millet is emphasized in Mali along with new cultivars with improved food quality traits. Major breeding activities involve the use of new genetic materials to develop cultivars to increase or stabilize yields of grain with enhanced food quality traits. Research methods appropriate for each of these are used in this research program.

Research Results

Details of some of the research related to Mali are presented in individual PI project reports in this publication. This Host Country Annual Report will emphasize research done by IER in Mali, SARI in Ghana, and ISRA in Senegal.

Sorghum Breeding

The sorghum breeding program in IER in Mali is a large and diverse program. The IER sorghum breeding program does extensive crossing and intercrossing among elite introductions, improved non-guinea and guinea derived breeding lines, and elite local cultivars. It utilizes genetically diverse germplasm from around the world resulting in much genetic diversity in the breeding program. Extensive use is made of ICRISAT developed lines and elite lines from the U.S. Emphasis in the program centers on developing tan-plant true guinea cultivars, and on improving the head bug/grain mold resistance of high yielding tan-plant non-guinea breeding lines and guinea by non-guinea intergrades. Essentially 100% of the breeding effort is directed to white-seeded, tan-plant genotypes. Breeding for the dry northern areas also involves crosses with local Durras from the area and early Caudatum derivatives from Senegal.

A standard system of moving progenies along at the different locations is in place and understood by the technicians. After the F_2, progenies are separated into early, medium, and late maturing groups and then selected and advanced at appropriate sites. Early materials are selected at the lower rainfall, more northern sites of Bema and Cinzana, while medium maturity materials are grown at Sotuba, Kolombada, and Cinzana. Late maturing progenies are evaluated mainly in the southern, high rainfall sites of Farako (Sikasso), Finkolo, and Kita. Yield trials of advanced breeding lines also are divided into these three general maturity groups and corresponding sites.

New breeding crosses are made annually to assure the gradual improvement of new breeding materials through recombination of the best materials. In the 2001 rainy season, 62 new crosses were made at Sotuba, and the F_1's grown during the 2001-02 off-season nursery to get F_2 seeds along with selected breeding lines for making new crosses.

From the multilocation evaluation of the 119 F2 families in 2001 520 single-plant selections were made to be advanced by the pedigree method. F_3 progenies (860 entries) were grown at Samanko, Cinzana and Béma with 346 panicles selected. The F_4 and F_5 generations were evaluated according to maturity group. The early and medium F_4 progenies were evaluated together this year at Sotuba, Kolombada, Béma and Cinzana with 308 panicles selected among 50 families. The late F_4 progenies were evaluated at Finkolo and Kita with 52 panicles selected. From 843 F_5 generation progeny rows a total of 40 early (Bema and Cinzana), 82 medium (Sotuba and Kolombada), and 44 late (Longorola and Kita) panicles were selected. The F_5 selections move to the off season for seed increase for entry into yield trials the following year.

Yield trials of improved varieties in 2001 were divided into three maturity groups, Early, Medium, and Late with three groups (GI, GII, GIII) within each maturity corresponding to the years in tests (I - first year, II - second year, III - third year). Evaluation was for maturity, yield, agronomic desirability, and food quality.

Advanced Early Variety Trials

In GI at Cinzana there was a significant difference among entries with the highest yielding varieties being 00-BE-F5P-33 (3333 kg ha^{-1}), 00-BE-F5P-135 (3056 kg ha^{-1}) 00-BE-F5P-29 (3000 kg/ha) and 00-BE-F5P-15 (3000 kg ha^{-1}). The first three are derived from (Malisor 84-7*nagawhite)*CEM326/11-5-1-1 while the last one is derived from a cross (Malisor 84-7*nagawhite)*Malisor 84-7. The mean test yield at Cinzana was 2230 kg ha^{-1}, with the local check producing 1222 kg ha^{-1}. At Bema the highest yielding varieties were 00-BE-F5P-71 (2695 kg ha^{-1}) which is derived from (Malisor 84-7*nagawhite)*CEM326/11-5-1-1 and Malisor 92-1 (2489 kg ha^{-1}).

In GII (two year evaluation) at Cinzana with significant differences among lines the variety 99-BE-F5P-122 derived from the cross (Sureno*85-F4-204)*N'Tenimissa ranked first with 2833 kg/ha against 2222 kg ha^{-1} for the local check and a test mean of 2127 kg ha^{-1}. At Béma there was no significant difference among entries for grain yield due to drought damage.

After three years of evaluation in the two locations (GIII), four lines 98-CZ-F5P-31-1, 98-CZ-F5P-18, 98-BE-F5P-24, and 98-CZ-F5P-83 will be in on-farm test this growing season (Table 1).

Advanced Medium Variety Trials

In GI at Sotuba, the variety 00-SB-F5DT-5 ((Malisor 84-7*nagawhite)*CEM326/11-5-1-1) ranked first with 3666 kg ha^{-1} followed by 00-SB-F5DT-18 (3250 kg ha^{-1}) with the same pedigree. The grain yield was 1583 kg ha^{-1} for the local check with a test mean of 1739 kg ha^{-1}. At Kolombada the average yield was lower (1088 kg ha^{-1}) with the highest yielding variety 00-SB-F5DT-18 ((Malisor 84-7*nagawhite)*CEM326/11-5-1-1) with 1846 kg ha^{-1}. In GII at Sotuba and Kolombada, there was no significant difference among entries for grain yield.

After three years of evaluation in the two locations (GIII), the three highest yielding varieties are 98-SB-F5DT-4 (Bimbiri soumale* N'Tenimissa) with 2286 kg ha^{-1}, 98-SB-F5DT-23 (CSM 388*(Bimbiri soumale*ICSV-1034)) with 2470 kg ha^{-1} and 98-SB-F5DT-14 (Bimbiri soumale* N'Tenimissa) with 2209 kg ha^{-1} (Table 1), and were selected for on-farm-testing next year.

Advanced Late Variety Trials

In GI at Finkolo, with an average yield of 1875 kg ha^{-1}, the highest yielding varieties were 00-KI-F5T-47 derived from the cross (N'Tenimissa * Local Tamala) with 3933 kg ha^{-1}, Foulatiéba (3900 kg ha^{-1}) and 00-KI-F5T-32-1 (2933 kg ha^{-1}). At Kita there was no significant differences among entries with an average yield of 1600 kg ha^{-1}. In GII at Finkolo the variety 97-SB-F5DT-150 ranked first with 2142

Table 1. Mean performance data from selected improved varieties from sorghum yield trials, Mali, 1999-2001.

Designation	Pedigree	Days to 50% flowering	Plant height (m)	Grain yield (kg/ha)
Early - GIII (3 years - 2 locations)				
98-CZ-F5P-18*	((Bimbiri S.*S34,)*Malisor 92-1)	76	2.4	2654
98-CZ-F5P-31-1*	((A Var *98-SB-F6-GII-2073)*Bimbiri S.)	73	3.2	2558
98-BE-F5P-24*	((Bimbiri S.*S34)*CSM388)	72	2.6	2347
98-CZ-F5P-83*	((Bimbiri S.*S34)*CSM219)	74	2.1	2307
CSM 63E	Check	66	2.9	1675
Local check		74	3.4	1702
(Test Mean)		74	2.5	2041
Medium - GIII (3 years - 2 locations)				
98-SB-F5DT-23*	(CSM388*(Bimbiri S.*ICSV1034))	84	3.2	2470
98-SB-F5DT-4*	(Bimbiri S.*N'Tenimissa)	85	3.6	2286
98-SB-F5DT-14*	(Bimbiri S.*N'Tenimissa)	83	2.9	2209
98-SB-F4DT-44		90	1.9	2088
CSM 388	Check	88	3.7	2157
Local check		86	3.6	2111
(Test Mean)		87	3.3	1914
Late - GIII (3 years - 2 locations)				
97-SB-F5DT-74-1	(N'Tenimissa*Tiemarfing)	86	3.4	1622
97-SB-F5DT-74-2	(N'Tenimissa*Tiemarfing)	87	3.4	1583
98-FA-F5T-41		86	3.6	1600
Foulatieba	Check	90	3.4	1911
Local check		91	3.5	1483
(Test Mean)		88	3.4	1614

* = Entries to be advanced to on-farm trials in 2002.

kg ha^{-1} against 633 kg ha^{-1} for the local check and a test mean of 1140 kg ha^{-1}. At Kita there was no significant difference among entries for with an average grain yield of 3218 kg ha^{-1}. After three years of evaluation in the two locations, there was no significant difference among entries for grain yield (Table 1).

On-Farm Trials

Three early maturing varieties were compared to the local check by 6 farmers at three locations, Cinzana, Sirakorola, and Didiena. For varieties in their second year of evaluation, there was no significant yield difference, but at Cinzana 98-BE-F5-84 and 96-CZ-F4P-12 produced excellent tô quality. At Sirakorola and Didiena 98-BE-F5P-84 and 97-SB-F5DT-65 was appreciated for earliness, grain quality and plant height, while 96-CZ-F5P-12 was appreciated for stalk quality for animal feed.

Two early varieties, 97-SB-F5DT-63 and 97-SB-F5DT-64 (N'Tenimissa*Tiemarfing) were evaluated for their third year by 6 farmers at three locations. Although there was no significant difference for grain yield, 97-SB-F5DT-63 was particularly promising and was appreciated by farmers enough that they named it "Uassa" (means 'satisfaction' in Bambara). It's main advantage over N'Tenimissa is whiter, higher quality grain.

For medium maturity varieties, 6 farmers at Ouelessebougou and Banocoumana evaluated three varieties for the second year. There was no significant difference in grain yield, but at Ouelessebougou farmers appreciated 97-SB-F5DT-76-2 for its drought resistance and suitable maturity. At Bancoumana, 97-SB-F5DT-76-2 was appreciated for its maturity while 97-SB-F5DT-150 was appreciated for its grain and stalk qualities.

Six farmers evaluated 98-SB-F2-78 for the third year. While not significantly different in yield, it was desired by farmers for its tô quality, drought tolerance and fast grain filling.

For late-maturing on-farm trials, 6 farmers at Kita and Finkolo evaluated seven new varieties with their local check. At Finkolo, all 7 varieties produced significantly higher grain yield than the local check (Table 2). At Kita the top three varieties were not significantly different from the local check.

Table 2. Mean of late maturity varieties for grain yield on on-farm test at Finkolo, Mali, 2001.

Designation	Grain yield kg ha^{-1}
97-FA-F5T-51	1954 a
97-FA-F5T-53	1807 a
97-SB-F5DT-74-1	1807 a
97-SB-F5DT-74-2	1856 a
97-CZ-F4P-98	1801 a
96-CZ-F4P-99	1874 a
97-SB-F5DT-154	1783 a
Local Check	1293 a
Mean	1772 b
CV%	7.7
Significance	**

Hybrid Sorghum - Mali

The cooperative hybrid research of IER and ICRISAT funded by the Rockefeller Foundation continued with the evaluation of breeding lines and local cultivars for restorer (B/R) reaction, and the presence of B_1. Sterilization of B-lines through backcrossing continued. Most U.S. and ICRISAT A-lines are dominant B_2, so recessive B_1 is needed when using these females in order for the grain of the hybrid to not have a testa. Some new Malian breeding lines were evaluated for their fertility reaction and B gene status.

West Africa Sorghum Breeding Observation Nursery (WASBON)

This nursery was divided into three maturity groups, early, medium, and late. Seed was assembled, tests packaged and distributed by Dr. Aboubacar Toure in Mali. The early test contained 16 entries from Mali, 21 from Niger, and 11 from Nigeria, and was sent to Mali, Niger, Senegal, Ghana, Burkina Faso, and Nigeria, as per requests from local scientists. In the 48 entry Early Trial at Cinzana in Mali, the top performers were 90SN-5, 90SN-3 and 90SN-1from Niger, and KSV11 and Samsorg 41 from Nigeria with yields ranging from 2250 to 2563 kg ha^{-1} compared to the test mean of 1521 kg ha^{-1}. At Nyankpala, Ghana, the top six performers were KSV12, KSV111, KSV400, and Samsorg 41 from Nigeria, 90SN-7 from Niger, and 98-SB-F4DT-52 from Mali. Their yields ranged from 1252 to 1501 kg ha^{-1} compared to the test mean of 990 kg ha^{-1}. In Senegal, the 48 entry WASBON was evaluated at Bambey, with yields ranging from 900 to 4700 kg ha^{-1} with a test mean of 2707 kg ha^{-1}. Based on vigor, cycle length, height, grain mold, and grain quality, 8 lines were selected for further testing and 6 others selected for use in crosses.

The Medium maturity nursery contained 29 genotypes, with 20 from Mali, 5 from Nigeria, and 4 from INTSORMIL (Texas A&M). In Mali at Sotuba, the top 7 genotypes were KL-2 (4567 kg ha^{-1}) and Farar Dawa (3133 kg ha^{-1}) from Niger, 97-SB-F5DT-56 (2467 kg ha^{-1}) and 97-SB-F2-78 (2210 kg ha^{-1}) from Mali, and Sureno (2933 kg ha^{-1}) and 90EON328 (2167 kg ha^{-1}) from Texas A&M. The test mean was 1780 kg ha^{-1}. In Ghana at Nyankpala there was tremendous variation in height and maturity. Grain yields were greatly reduced by drought and midge. The very late lines were severely damaged by midge. Grain yields ranged up to 2516 kg ha^{-1} with a test mean of 1577 kg ha^{-1}. Lines ICSV905 and Farar Dawa from Nigeria produced outstanding yields, but the performance by entry was non-readable on the e-mail. Another year of testing will be required before meaningful selection can be done.

In the Late maturity test, there were 9 entries from Mali and 7 from Nigeria. In Senegal, yields were low due to poor stands, short rainy period, birds, and the very late maturity of most entries. Five lines, 97-FA-F5T-53, 97-SB-F5DT-154, 98-KI-F5T-45, 98-FA-F5T-37, and 98-FA-F5T-41, all from Mali were retained for further testing. In Ghana, the late test entries yielded less than the medium maturity entries, with 96-CZ-F4P-99 (1127 kg ha^{-1}), 96-CZ-F4P-98 (1088 kg ha^{-1}), and 98-KI-F5T-45 (1075 kg ha^{-1}) all from Mali produced the highest yields with a test mean of 746 kg ha^{-1}.

Other Sorghum Breeding Activities

Senegal

Other breeding research involved evaluation of 74 F_4-F_6 Guinea derivative families from ICRISAT with 17 selected for further evaluation. Two regional ICRISAT trials of guinea lines were also evaluated but not selected due to their excessive height and average yields. From the INTSORMIL West Africa Drought Test, 3 entries were found to be superior, TX7000, Macia, and the hybrid Hageen Dura 1. From the 50 entry Elite Germplasm Nursery assembled by TAM-222 in Texas, 9 lines were selected for further use; MP531, S-34, ICSV401, Sureno, (ICSV401*S34), ZSV15, KAT 83369, 82-F4-164, and (E36-1*M84-7)-5-1.

Ghana

Due to late and erratic rainfall coupled with the early cessation of the rains, general performance of sorghum trials was poor. The West Africa Drought Test was lost due to poor stands. The INTSORMIL trial, ADIN (All Disease and Insect Nursery), was also evaluated and some data on disease reaction obtained for grey leaf spot and leaf blight. One ADIN entry, SC326-6, was found to be severely attacked by bacterial leaf stripe (*Burkholderia andropogonis*), a quarantine pathogen of sorghum in Ghana. The performance and disease reaction of the WASDON (West Africa Sorghum Disease Observation Nursery) is presented in Table 3.

Millet Breeding

Mali

Trials were conducted to evaluate the performance of population hybrids among West Africa landraces and to determine if cycle of recombination had an effect on performance. Twenty-five population hybrids were evaluated and compared with three local check cultivars. The hybrids were all earlier in flowering, shorter in height, and were severely damaged by birds compared to the check cultivars Boboni, Toroniou C1, and SoSat. The resulting grain yield of the hybrids was much lower, generally about 1,000 to 1,100 kg ha^{-1} compared to 2620, 2305, and 1575 kg ha^{-1} for the locals. From 30 to 50% of the panicles were emptied by bird attack in the hybrids. WA16 showed potential due to its head length and high number of tillers. Delayed sowing by 7 to 10 days may allow the new varieties to avoid bird damage.

In the recombination cycle study among two pedigrees, ExBorno*Ugandi, and ExBorno*Mansori, there was no dif-

Table 3. Performance data and field reactions[1] of sorghum genotypes (WASDON) to different diseases at Nyankpala, Ghana, 2001.

Entries	Origin	Days to 50% flowering	Plant height (cm)	Grain yield (kg ha^{-1})	Grey leaf spot	Leaf blight	Grey leaf spot on panicle	Bacterial leaf stripe
SAMSORG 14	IAR, Nigeria	93	365	373	4.0	1.0	3.0	1.0
SAMSORG 40	“	93	202	973	1.0	2.0	1.0	1.0
SARIASO-01	INERA, Burkina	91	378	2040	4.0	1.0	4.0	1.0
SARIASO-02	“	88	341	813	5.0	1.0	6.0	1.0
OUEDZOURE	“	95	447	1987	4.0	1.0	4.0	1.0
SC326-6	Texas, USA	99	135	520	1.0	1.0	1.0	8.0
VG 153	“	87	192	1667	1.0	4.0	1.0	1.0
SURENO	“	95	176	320	1.0	3.0	1.0	1.0
9GW092	“	87	124	400	1.0	5.0	1.0	1.0
90L19178	“	86	197	1400	1.0	3.0	1.0	1.0
98-FA-EART-101	IER, Mali	99	154	440	1.0	3.0	1.0	1.0
98-SB-F5-DT-25	“	92	342	493	2.0	1.0	2.0	1.0
98-SB-F5-DT-59	“	87	365	1640	1.0	3.0	1.0	1.0
98-SB-F5-DT-4	”	86	355	2000	1.0	4.0	1.0	1.0
98-KO-F5-DT-39-2	“	87	366	1960	1.0	3.0	1.0	1.0
98-KI-F5-T-45	”	90	351	813	1.0	4.0	1.0	1.0
98-F2-82	“	92	177	1160	1.0	2.0	1.0	1.0
97-SB-F5-DT-154	”	93	139	1280	1.0	4.0	1.0	1.0
97-SB-F5-DT-160	“	93	145	267	1.0	4.0	1.0	1.0
F2-78	”	91	129	1133	1.0	3.0	1.0	1.0
97-SB-F5-DT-150	“	95	127	427	1.0	5.0	1.0	1.0
97-SB-F5-DT-151	”	99	152	293	1.0	1.0	1.0	1.0
FOULATIEBA	“	92	421	2200	4.0	1.0	2.0	1.0
IS 18442	ICRISAT, Mali	86	287	920	6.0	1.0	6.0	1.0
A2267-2	“	91	225	867	1.0	3.0	1.0	1.0
Mean[2] (25 entries)		91.5	251.6	1055.5	1.9	2.6	1.8	1.3
CV (%)		2.6	5.7	50.3				

1 Based on rating scale 1-9: 1 = no disease; 2 = 1-5%; 3 = 6-10%; 4 = 11-20%; 5 = 21-30%; 6 = 31-40%; 7 = 41-50%; 8 = 51-75% and 9 = > 75% of leaf area of the plant or panicle parts damaged by the disease.
2 Mean of two replications.

ference in grain yield with up to three recombination cycles compared to the open pollinated.

Senegal

Two advanced yield trials with 10 and 6 lines respectively were conducted in Bambey. Two new synthetics of the Senegal program ISMI9507 (3009 kg ha^{-1}) and ISMI 9503 (2821 kg ha^{-1}) significantly out-yielded the check IB 8004 (1875 kg ha^{-1}) in the first trial with mean 2302 kg ha^{-1}. The 3-year (95, 96, 01) mean yield of ISMI 9507, 9506, 9503 was respectively 37.4%, 35.4%, and 32.7% higher than the checks.

In the second trial, the highest yielder was the check IBMV 8402 (2858 kg ha^{-1}) and is followed by a new synthetic ISMI 9305 (2656 kg ha^{-1}) and IBV 8004 (2595 kg ha^{-1}). Yield of these varieties was not significantly different. However, the 5-year (93, 94, 95, 96, 01) mean yields show that ISMI 9301, 9303, 9305 are superior to the variety IBV 8004 with up to 16% higher yields. Seeds of the new synthetics will be multiplied and introduced in on farm test.

Striga

A West Africa *Striga* Nursery was developed for 2001 with entries solicited from all INTSORMIL collaborating countries. Seventeen entries were received from Mali, Nigeria, Burkina Faso, and USA. Seed was assembled in Mali and distributed to interested countries. Results from the replicated trials were received from Mali, Nigeria, Senegal, and Ghana. Data from Cinzana and Sotuba, Mali, and Samaru, Nigeria are presented in Table 4.

In Ghana two trials were planted with one lost to drought. Data on the 16 varieties is shown in Table 5 with generally a high level of resistance. CE151-262-A1 had no infestation throughout the season but the grain was destroyed by midge. 097-SB-F5DT-64 combined high yield with low *Striga* infestation. N'Tenimissa, Samsorg 14, and IS7777 appeared to be most susceptible.

In Senegal, under field evaluation where pearl millet had been grown continuously, *Striga* emergence was the highest on CE151 with 10 pl/m^2, while all other lines had less than one. CMDT38, Malisor 92-1, Malisor 84-1 and Samsorg 41 were free of *Striga* throughout their cycle. In a screen house with artificial inoculation of *Striga* seed harvested from a sorghum field, *Striga* plants first appeared on CMDT-39 at 43 days and CMDT-38 at 45 days. These two plus CMDT-45 had the highest number of *Striga* plants with 9, 11, and 12, respectively. *Striga* appeared the latest on Seguetana (80 days) and was the attacked along with Malisor 92-1 with only two emerged on each. These results suggest that millet and sorghum are attacked by different biotypes.

Overall, results seem variable with some rather major switches in reaction over location such as with CE151 and Samsorg 41. The Mali improved local Seguetana appeared quite resistant across locations. The trials will be repeated in 2002.

Agronomy

Mali-Sorghum

On-farm research to assess the nutrient availability in Malian soils was conducted in 2001 in three villages each in the Bougouni and Kita areas. Sorghum yield response to various fertilizer treatments was evaluated, using NPKS compared to (-P), (-N), (-S), (-K), and check (no fertilizer).

Table 4. Performance data from the 2001 West African *Striga* Nursery, Mali and Nigeria.

		Cinzana				Sotuba			Samaru, Nigeria						
Variety Designation	Country of origin	Days to 50% flower	Plant height (m)	*Striga* incidence	Grain yield (kg ha^{-1})	60 days	75 days	90 days	9 weeks	11 weeks	Harvest	9 weeks	11 weeks	Harvest	No. *Striga flowers* at harvest
CMDT-38	Mali	73	3.3	1	1184	1	1	1	3.7	9.7	21.7	1.0	4.0	9.7	18.7
CMDT-39	Mali	74	3.3	1	667	3	3	3	1.7	4.7	17.7	1.3	3.3	10.3	16.3
Seguetana	Mali	78	3.2	1	1481	1	0	0	0	3.0	9.3	0	2.3	6.0	9.3
CMDT-45	Mali	73	3.5	1	1037	3	2	3	1.7	12.0	28.3	0.7	4.7	15.7	28.0
97-SB-F5DT-63	Mali	72	3.4	1	1481	4	5	4	0	0	2.0	0	0	2.0	2.0
97-SB-F5DT-64	Mali	72	3.0	1	1037	3	2	5	0	0	1.3	0	0	1.0	1.7
N'Tenimissa	Mali	74	3.4	2	963	4	5	5	0	0.7	4.7	0	1.0	4.3	4.3
97-SB-F5DT-65	Mali	74	3.1	1	1185	4	5	5	0	0.7	6.0	0	0.3	5.3	4.3
Malisor 92-1	Mali	71	1.8	2	1556	5	6	7	0.3	0.7	2.7	0.3	0.7	2.3	2.3
Malisor 84-1	Mali	66	1.8	1	1556	3	3	2	0.3	3.0	7.3	0.3	2.7	3.3	6.7
CE151-262-A1	US/Senegal	73	1.3	3	1407	7	9	7	0.3	3.7	8.0	0.3	2.0	4.3	7.7
SRN39	US/Purdue	64	1.2	1	889	3	5	4	0	0	0.7	0	0	0.7	0.7
Samsorg 41	Nigeria	65	2.0	1	1556	17	30	4	0	0.7	0.3	0	0.7	0.3	0.3
Samsorg 14	Nigeria	82	2.8	3	815	10	18	20	1.7	9.0	26.7	1.3	6.0	13.3	26.7
Sariaso 1	Burkina Faso	87	3.4	4	593	4	6	8	—	—	—	—	—	—	—
Sariaso 2	Burkina Faso	89	3.2	4	222	8	7	8	—	—	—	—	—	—	—
IS7777	US/Purdue	—	—	2	148	—	—	—	—	—	—	—	—	—	—
KP33-2	US/Purdue	60	0.9	4	709	2	0	2	—	—	—	—	—	—	—
Mean				1.91	1027	4.8	6.0	5.5							
CV (%)				31.8	46.3										
Significance				**	**	NS	NS	NS	NS	NS	*	*	*	*	*

* Number of *Striga* plants in plot

Table 5. Performance of selected sorghum varieties in *Striga* infested field at SARI, Ghana in 2001.

			Striga count 28 days		*Striga* count 42 days		*Striga* count at harvest			
Designation	Days to flower	Plant height (cm)	Raw	Transformed[1]	Raw	Transformed[1]	Raw	Transformed[1]	Psmicle weogjt kg ha^{-1}	Grain weight lg ha^{-1}
CMDT-38	86	171	0.00	0.707	0.33	0.880	7.33	2.735	1534	568
CMDT-39	88	203	0.33	0.880	1.67	1.386	8.33	2.965	1187	578
SEGUETANA	84	192	0.00	0.707	2.67	1.738	9.00	3.063	1084	472
CMDT-45	85	207	0.67	1.052	7.00	2.735	32.00	5.695	1455	711
97-SB-F5DT-63	87	187	0.00	0.707	5.00	2.262	27.67	5.228	1768	395
97-SB-F5DT-64	86	209	0.00	0.707	0.33	0.880	6.00	2.529	5284	2232
N'TENIMISSA	87	223	2.00	1.470	11.67	3.480	47.33	6.910	1494	474
97-SB-F5DT-65	83	193	0.00	0.707	0.00	0.707	2.33	1.544	1673	690
MALISOR-92-1	76	159	0.00	0.707	3.33	1.932	12.33	3.560	1214	1011
MALISOR-84-1	76	165	0.00	0.707	0.00	0.707	2.00	1.470	1333	627
CE-151-202-A1	87	142	0.00	0.707	0.00	0.707	0.00	0.707	-*	-*
SRN 39	78	146	0.00	0.707	0.33	0.880	2.33	1.544	1218	362
SAMSORG 41	77	149	0.00	0.707	0.67	0.998	17.67	4.214	-*	-*
SAMSORG 14	89	167	1.00	1.171	9.33	3.091	45.00	6.723	2120	733
33-2	89	102	0.00	0.707	6.67	2.671	13.67	3.744	-*	-*
IS 7777	89	177	1.00	1.171	6.67	2.617	39.00	6.283	1459	341
Grand Mean	84	175	0.313	0.845	3.48	1.729	17.00	3.682	1756	707
CV(%)	2.0	2.0	210	31.2	51.8	22.2	26.4	15.1	73.2	56.5
LSD(0.05)	3	6	1.10	0.439	3.00	0.640	7.491	0.925	2164	673.8

[1] Square Root Transformation of original values
* These did not produce any harvestable heads and were not included in the analysis of those parameters.

At Bougouni, low and erratic rainfall resulted in low yields. Although not significant, the grain and stover production tended to be lower when various nutrients were eliminated (Table 6). In the Kita area, grain and stover yields were reduced whenever nutrients were withheld, except for potassium, with grain yields being significantly different (Table 6). In both regions, phosphorus appears to be the most limiting nutrient in the soil and potassium the least limiting soil nutrient. Village fertilizer interactions were not significant in either region.

Mali-Acid Soil

Several exotic sorghum genotypes, promising breeding lines, local cultivars, and improved varieties were tested for tolerance to acid soils in a naturally occurring toxic plot on the Cinzana Station in 2000 and 2001. Data on the survival of healthy plants are presented in Table 7. Local cultivars well adapted to low rainfall, sandy soils, (and presumably acid soils) from Niger, Mali, and Nigeria have shown good performance over several years. However, all are Durra or Caudatum types and do not have acceptable grain quality traits for use in the major production zones of West Africa where Guineense type sorghums are commonly used. Seedlings of some of the improved, exotic, and new breeding genotypes appear to show a useful level of tolerance, including N'Tenimissa, the new white-seeded, tan-plant Guinea types cultivar recently developed and released by IER in Mali.

Mali-Cinzana

A study of effectiveness of microdoses of inorganic fertilizer on millet production on sandy soils was initiated in 2001 at Cinzana. The recommended dose of chemical fertilizer is not economical to farmers in the context of the current free market prices. Microdoses, if successful, would reduce

Table 6. Sorghum yield response to fertilizer treatments in on-farm trials in villages in the Bougouni and Kita areas of Mali, 2001.

Fertilizer[1/] treatment	Stover kg ha^{-1}	% of NPKS	Grain kg ha^{-1}	% of NPKS
Bougouni Region				
NPKS	19184	100	698	100
NPS(-K)	15790	82	866	124
NKS(-P)	10645	55	391	56
NPK(-S)	13909	73	580	83
PKS(-N)	14141	74	675	97
Check	13163	69	396	57
	NS		NS	
Kita Region				
NPKS	6818	100	3054a	100
NPS(-K)	7671	113	3433a	112
NKS(-P)	5587	82	2249b	74
NPK(-S)	6132	90	2983ab	98
PKS(-N)	5185	76	2657ab	87
Check	3291	48	2438 b	80
	NS		*	

[1/] N = Nitrogen, P = Phosphorus, K = Potassium, S =Sulfur

Table 7. Percentage of planting hills containing at least one healthy plant at different stages.

Sorghum cultivar		50% flowering 2001	Physiological maturity 2001	Physiological maturity 2000
El Mota	Local (Niger), acid soil tolerant, Caudatum	100	100	100
Bagoba	Local (Niger), acid soil tolerant, Durra	94	90	71
Gadiaba/CZ	Local (Mali), acid soil tolerant, Durra	90	87	63
Kenike-ba	Local (Mali), acid soil tolerant, Guinea	56	55	57
Malisor 84-5	Improved (Mali), acid soil susceptible	17	14	20
OH84-3/5	Local (Nigeria), acid soil tolerant, Durra	54	52	67
IS 3553	Exotic, accum. low Mn	98	98	100
IS 6902	Exotic, Accum. high Mn	47	23	36
IS 8577	Exotic, accum. low P	47	21	29
IS 9138	Exotic, accum. high Si	34	19	33
IS 9277	Exotic, accum. low Mn	74	74	59
MN 4508	Exotic, accum. high Al	46	46	48
SRN 39	Exotic, Striga tolerant	79	74	88
97-BE-F5P-4	Mali promising new breeding line	64	58	69
97-SB-FS-DT-63	Mali promising new breeding line	53	52	49
97-SB-F5-DT-74-2	Mali promising new breeding line	56	56	51
98-SB-F2-78	Mali promising new breeding line	70	62	57
98-SB-F2-82	Mali promising new breeding line	53	51	41
98-BE-F5P-84	Mali promising new breeding line	49	48	58
N'Tenimissa	Improved released Guinea Cultivar (Mali)	85	82	71

the total fertilizer needed per unit area. Microdose fertilizer (2 grams of Di-Ammonium Phosphate) per hill was applied at planting. Data in Table 8 indicates that all the treatments produced more grain, biomass, and panicles than the control. The microdose treatment alone resulted in a significant increase in production, while the addition of 20 kg ha^{-1} of P+ 30 kg ha^{-1} of N or 40 kg ha^{-1} of P+ 60 kg ha^{-1} of N produced the most grain, biomass, and panicles. The addition of supplemental P to a microdose resulted in greater millet production than the addition of only supplemental N. However, the addition of both P and N had the greatest synergistic effects on overall millet production. These preliminary results indicate, that the application of microdoses alone is not sufficient to give full millet grain and biomass under the 2001 conditions.

Microdose treatments and recommended fertilizer on millet and sorghum on heavy soil had no significant effect on growth and yield. This may have been due to the very bad distribution of rainfall with severely stressed plant growth during the flowering stage greatly reducing yields.

Ghana-Sorghum

With phosphorus deficiency being a major limiting factor in crop production, research was conducted to look at the effect of phosphorus application in a sorghum-cowpea rota-

Table 8. Effect of microdoses on millet grain and biomass production on sandy soil at Cinzana, 2001.

Treatments[1/]	Number of panicles/ha (at harvest)	Biomass yield Kg ha^{-1}	Panicle yield Kg ha^{-1}	Grain yield Kg ha^{-1}	Plant population at harvest/ ha
T1	20312	1458	604	390	25729
T2	20312	2995	1073	608	35208
T3	26458	3151	1104	671	31562
T4	29479	4323	1271	765	36042
T5	29375	3281	1062	640	40312
T6	28646	3411	1167	681	38333
T7	39687	4375	1635	962	46771
T8	38646	5312	1604	890	54429
Significance	**	**	**	**	**
LSD	6639	1130	331	225	6720
C.V.(%)	14.9	21.7	18.9	21.8	11.8

* T1 = Control (no fertilizer)
T2 = 2gr of DAP
T3 = 2grDAP+20kg/ha of TSP
T4 = 2grDAP+40kg/ha of TSP
DAP = 2 grams of Di-Ammonium Phosphate per hill
TSP - Triple Super-Phosphate

T5 = 2grDAPP+30kg/ha Urea
T6 = 2grDAP+60kg/ha Urea
T7 = 2grDAP+20kg/haTSP+30kg Urea
T8 = 2grDAP+40kg/haTSP+60kg Urea

Table 9. Sorghum and cowpea yields and yield components as affected by P fertilizer rate and frequency, Wa, 2002.

	Sorghum			Cowpea			
Frequency of P application	Stover yield kg ha^{-1}	Kernels no. m^{-2}	Grain yield kg ha^{-1}	Stover yield kg ha^{-1}	Seed no. m^{-2}	Pod weight kg m^{2}	Grain yield kg ha^{-1}
Cumulative	3901	8761	2309	2720	1516	288	1870
Direct	3703	8195	2155	2533	1471	277	1809
Residual	3310	7871	2105	2556	1370	246	1696
	NS	NS	NS	NS	NS	NS	NS
P rate (kg/ha)							
0	3110	5978	1428	2012	1070	192	1272
30	3330	8847	2195	2824	1549	278	1885
60	4027	9039	2512	2817	1575	302	1983
90	4091	9239	2625	2761	1615	309	2022
Significance	0	**	**	**	**	**	**
CV(%)	28.0	20.1	23.7	19.7	13.4	15.2	13.7

tion at the Wa station. Treatments were three frequencies of P application: (1) Direct (applied to the current crop); (2) Residual (applied to the preceding crop); and (3) Cumulative (applied to both current and proceeding crops - both sorghum and cowpea). Also, sorghum plots received a uniform application of 40 kg N/ha each year. Both sorghum and cowpea grain yields and yield components responses to frequency of P application were negligible and not significant (Table 9). Added P fertilizer at the various rates, and under the frequencies mentioned above increased grain and stover production in both sorghum and cowpea. On average, the greatest net benefits (per ha) were obtained from residual P fertilizer. The results so far suggest that there is no need to apply P fertilizer on an annual basis when sorghum and cowpea are grown in rotation.

In another agronomy trial on the Wa Station, the effect on sorghum of rotation with three legumes, cowpea, peanut, and soybean, and different N rates was studied. All plots received a uniform application of Phosphorus at 30 kg ha^{-1}. Sorghum following any legumes produced significantly higher grain yield, averaged across all N rates. Sorghum grain yields following the previous crop were Cowpea - 2760 kg ha^{-1}; Peanut - 3101 kg ha^{-1}; Soybean 2775 kg ha^{-1}; and Sorghum - 2262 kg ha^{-1} with LSD of 333 kg ha^{-1}. Likewise, N fertilization had a significant effect on sorghum grain production averaged across all rotations with grain yields of: ON - 1737 kg ha^{-1}; 4ON-2561 kg ha^{-1}; 8ON-3191 kg ha^{-1}; and 120N-3409 kg ha^{-1}. The greatest effect was on kernal number rather than size. The response of grain yield of sorghum to previous crop and N rates is presented in Figure 1.

A third agronomy experiment at Wa studied the effect on sorghum of crop residue management (0, 50, and 100% of stover return) and fertilizer use (0 versus 64-38-38 kg ha^{-1} of N, P_2O_5 and K_2O. Crop residue return rate had no effect on sorghum production, while fertilizer increased grain yield by 1183 kg ha^{-1} (224% more grain) over unfertilized plots averaged across crop residue rates. This experiment as well as the other two discussed above will be continued in 2002.

Pathology

Mali

Out of 180 sorghum breeding lines or improved cultivars screened for anthracnose at Sotuba, only the following showed good resistance: 00-K0-F5-80,, 99-SB-F5-DT-51, 99-SB-F5-DT-188, 99-SB-F5-200, 98-SB-F5-DT-25, 98-SB-F5-DT-59, 98-KI-F5T-45, 98-SB-F2-7 (all from

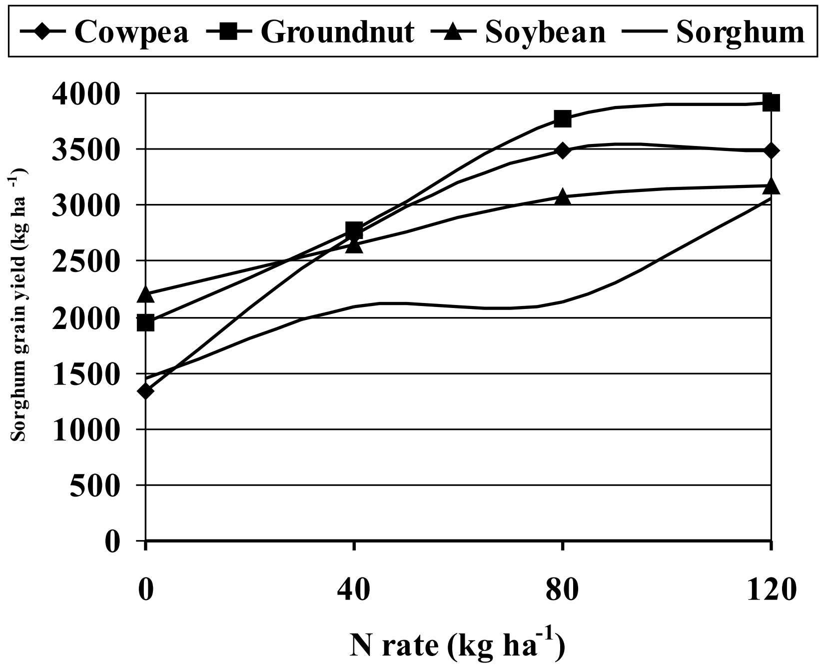

Figure 1. Grain yield of sorghum as influenced by previous crop and different rates of fertilizer N rates, Wa, Ghana, 2001.

Mali), and Ouedzoure from Burkina Faso. In the ADIN, most accessions showed resistance to leaf anthracnose except RTx2914 (88B943), Tx2911 (92B1941), and TAM 428 and most accessions were susceptible to sooty stripe. In the ISAVN (International Sorghum Anthracnose Virulence Nursery), Tx2536 and SC414-12E showed good resistance to leaf anthracnose. This contrasted some with anthracnose ratings on the ISAVN of Samaru, Zaria, Nigeria where Tx2536 was rated as susceptible, while SC326-6, IS18760, SC748-5, and IS854 had a good deal of resistance, indicating the probable presence of different pathotypes of anthracnose in West Africa. This was also suggested in Senegal where at the two sites, Kolda and Sinthiou, some genotypes in the ISAVN showed different reaction to anthracnose namely IS18758, TAM 428, IS12567, SC120, Tx434, and IS6959. At Kolda, only a local check F2-20 was not affected, while at Sinthiou only IS18758, IS12467, SC120, and Tx2536 were diesase free.

In a study in 14 farmer fields at Kolokani and Banamba, the effect of seed treatment on the incidence of covered kerned smut was studied. DNN (Dire+Nguo+Néré) and Apron star, were evaluated on an improved variety and on farmer seed. All treated seed effectively controlled the smut and significantly increased grain yield from 53 to 64% over the farmer non-treated seed.

Some new research was initiated in 2001 cooperatively with John Leslie and Wally Marasses (South Africa) to evaluate the toxins from *Fusarium* spp. on grain samples from Mali.

Senegal

In Senegal, the ISAVN, WASDON (West Africa Sorghum Disease Observation Nursery), ADIN (INTSORMIL/Texas All Disease and Insect Nursery, and GWT (INTSORMIL/Texas Grain Weathering Test) were evaluated. Results of the ISAVN are presented above. In the WASDON, anthracnose, long smut, sooty stripe, and grain mold severity was low. In the ADIN at Kolda only 4 entries, 99GWO92 (86EO361*98E0343), OOCA 4654 (Sureño*SRN39), B8PR1059 (88B885*GB108B), and 96BCPOB143 (86EO361*GR107) along with the local check F2-20 were rated resistant to grain mold. Long smut, sooty stripe, and anthracnose severity was low at both sites. In the GWT, 30% of the entries were classed or susceptible while 20% showed moderate resistance, with the local F2-20 being the most resistant.

Ghana

The ADIN and WASDON were evaluated for grey leaf spot, leaf blight, and bacterial leaf stripe. Data from the WASDON are presented in Table 3. *Striga* counts on the ADIN show low numbers of 0 and 1 *Striga*/plot at harvest ranging up to a high of 16 for the entry 92BO1982-4.

Nigeria

Although not reported in detail here, the same INTSORMIL and West Africa trials ISAVN, ADIN, WASDON, WA *Striga* trial and the three WASBON trials (Early, Medium, and Late), were evluated in Nigeria. Some comments on the ISAVN are above in the Pathology (Mali) section, while the *Striga* data are presented in Table 4. The lines 97-SB-F5-DT-63, 97-SB-F5-PT-64, Malisor 92-1, SRN 39, and SAMSORG 41 (ICSV111) showed low *Striga* infestation and a low number of infected plants, thus showing good field resistance. CMDT-38, -39, and -45, along with SAMSORG 14 had high *Striga* infestation. However, SAMSORG 14 gave the highest grain yield indicating a high level of tolerance. In the ADIN, SC326-6 and 91BE7414 showed the best resistance to foliar anthracnose. It was interesting that BTx378 was moderately susceptible, and Tx7078 and TAM428 were moderately resistant, all the opposite of anthracnose ratings in Texas. In the WASDON, SAMSORG 14 showed the highest resistance, followed by A2267-2, SC326-6, 99GW092, 90L19178 with good resistance.

Entomology

Various trials were planted at several locations and at different dates to evaluate resistance to sorghum midge, head bug, and aphid. A trial of 68 entries mostly from the U.S. was planted at Samanko. Fifty genotypes were planted on two dates at Kita, and 20 entries on two dates at Cinzana, with entries from U.S., ICRISAT, and Mali. Midge, headbug, and aphid infestations and damage were low at Samanko. Only 9 entries had midge damage ratings from 2 to 3, all others being 1.5 or 1.0. At Kita, midge damage also was very low with damage slightly higher in the second planting date those 12 entries had damage ratings of 2.0 to 2.8. AT Cinzana, the primary head bug screening location, the infestation of head bugs was relatively low compared to previous years, but there was some good difference among varieties. Data from Cinzana presented in Table 10 with a few entries showing a low damage rating similar to Malisor 84-7. Damage ratings ranged from 1.3 to 5.5 in data 1 and 1.4 to 6.3 in the second data.

In another study on midge damage assessment there was no significant damage on local or improved cultivars in five farmers fields in the Cinzana area.

The use of wood ash from two local plants, *Calotropus procera* and *Acacia nigricans*, to control the storage grain insect *Rhyzopertha dominica*, was studied. Both kinds of ash resulted in reduced insect emergence, with no difference between the two kinds of ash.

In Ghana, the ADIN were evaluated for shootfly and stemborer. Shootfly incidence was high with a wide range from low of 11.5% for B.LD6 to a high of 76.9% for 9BRON125.

Food Technology

Grain from the medium cycle Advanced Sorghum Variety Trials (Cycle I, II, and III) were evaluated for food quality traits including vitreousness, 1000 kernel weight, dehulling yield, tô consistency, tô color, KOH test, density, and ash. Although there was some variation, most of the advanced breeding lines from the IER breeding program rated good on food quality traits and compared favorably to local guinea cultivars and were deemed suitable for local food uses.

Diffusion of new products was another thrust of the food technology group. Training on the use of sorghum malt, a non-alcoholic drink was given to 50 women in two villages. Also work was done promoting sorghum syrup in supermarkets and couscous in African colonies in France and U.S.

The use of flour from the tan-plant cultivar N'Tenimissa continued to show great promise with use in the Deli-ken cookies marketed by GAM, and the marketing of 1 kg bags of sorghum flour called Sorgho Phar in markets in Bamako. Also, a considerable quantity of N'Tenimissa was success-

Table 10.Head bug adults, larvae and damage on 20 sorghum varieties at Cinzana, 2001.

	Planting date - July 23			Planting date - July 30		
Variety Designation	Mean No. larvae/ 5 panicles	Mean no. Adults/ 5 panicles	Head bug[1/] damage rating	Mean no. larvae/ 5 panicles	Mean no. adults/ 5 panicles	Head bug[1/] damage rating
CSM63	0.76	0	2.5	0.30	0.30	2.1
P99	0.74	0.31	1.3	6.19	1.42	2.3
ICSR14	5	33.57	4.5	5.83	4.16	3.5
ICSR15	3.33	8.33	5.5	0	0	4.5
DT120	9.73	0.52	4.5	25.55	3.33	5.5
PM2898	1.56	3.75	4.0	0	0	2
ICSV75	2.69	6.15	5	1.25	31.25	6
DT111	7.05	2.23	4.3	7.5	37.5	3.4
RSP110	0	10.0	5.15	12.29	7.29	5.0
ICSV13	6.47	4.11	4.8	18.42	11.56	4.3
M84-7	5.47	9.42	2.1	0.95	0.71	1.9
RST 107	2.89	6.84	1.8	9.37	3.12	2.5
RSP111	35.71	23.57	4.6	0	0	1.4
ICSV63	5.41	35.83	4.5	0	2.30	2.4
DT101	25.83	17.5	3.7	0	0	2.5
ICSR02	8.81	5.0	2.7	1.11	7.50	2.4
RSP112	1.56	2.81	2.5	5.71	55	3.6
Tx7000	5.33	6.66	4.4	110	250	6.3
DT 143	11	24	3.4	25.5	5.0	3.5
F2-79	32	8.83	4.3	0	0	2.5
Mean	8.56	10.4	3.77	11.49	21.02	3.38

[1] Damage raring where 1 - no damage to 9 extreme damage.

fully contracted for production with local farmers, and the Identity Preserved Grain marketed and made into flour by a private entrepreneur. The new tan-plant Guinea cultivars from the breeding program should be useful for such uses as they have slightly superior food quality to N'Tenimissa and are more agronomically susceptible.

Economics/Marketing

In an evaluation of the progress on Identity Preserved Marketing of N'Tenimissa, it was found that a local entrepreneur, Mr. Diawara was successful in producing through contracting 13.8 metric tons of N'Tenimissa grain from three villages. When the demand for N'Tenimissa flour from GAM declined due to the removal of tariffs on wheat, causing wheat prices to fall, the entrepreneur created an alternative market. He sold 1 kg bag of sorghum flour called Sorgho Phar for CFA 500 in markets in Bamako. The product was so popular that he had trouble keeping supplies stocked. Plans are to contract produce N'Tenimissa in four villages in 2002 with a goal of 100+tons of grain.

In his Ph.D. research, Jeffrey Vitale studied, under the supervision of John Sanders, the introduction of new technology in Mali. The study suggested that new technology in traditional cereals such as sorghum and millet would provide a greater increase in benefits compared to new technology introduction in the new cereals, maize and rice. Two advantages of the traditional cereals is that although the new cereals have higher productivity, traditional cereals have larger potential yield increases. Diminishing returns will likely accompany further technology introduction in the new cereals given the considerable intensification they have already experienced. The other advantage is that the traditional cereals require less stringent growing conditions. Mali's dry climate and poor soils are better suited to the traditional cereals, so benefits from new technology introduction in the traditional cereals would be realized over a wider area and extended to more farmers.

Institution Building

IER sorghum and millet programs received, through INTSORMIL collaboration, a vehicle, two computers, a printer, a copy machine, a fax machine and various field and laboratory research equipment and breeding supplies.

Many Malian scientists trained at INTSORMIL institutions are senior staff making important contributions in sorghum and millet research within the IER including:

Dr. Aboubacar Touré (Texas A&M) - Currently Sorghum Breeder, Mali National Coordinator for sorghum, Mali INTSORMIL Coordinator, and on INTSORMIL Technical Committee.

Dr. Mamourou Diourté (Texas A&M and Kansas State) - Currently Head Sorghum Pathologist.

Dr. Samba Traoré (Nebraska) - Currently Agronomist and Mali National Coordinator for Millet.

Dr. Niamoye Yaro Diarisso (Texas A&M) - Currently sorghum entomologist, and head of the Vegetable Station in IER.

Dr. Mamadou Doumbia (Texas A&M) - Currently Director of Soil Laboratory and soil scientist with IER.

Mr. Abdoul W. Touré (Nebraska) - Currently sorghum agronomist.

Mr. Sidi Bekaye Coulibaly (Nebraska) - Previously sorghum physiology/agronomy and sorghum breeding and INTSORMIL Coordinator. Currently working on Ph.D. at Texas A&M/Texas Tech.

Students currently in training include Niaba Témé who successfully completed his B.S. and is currently an M.S. student at Texas Tech University and Sidi Bekaye Coulibaly, who has served as INTSORMIL Host Country Coordinator, is now a Ph.D. student at Texas Tech/Texas A&M University. Karim Troaré, former IER millet and sorghum breeder is now a Ph.D. student at Texas A&M University.

Bocar Sidibé, Abocar Toure, Kissima Traore, Sibène Déna, and Moussa Sanogo received short term training in the U.S. provided by INTSORMIL in breeding and plant pathology.

Dr. Aboubacar Toure, sorghum breeder, is a member of the streering committee of the West and Central Africa Sorghum Research Network, WCASRN (ROCARS).

U.S. scientists traveling to Mali included: Dr. Carl Nelson (April, 2002), Dr. John Leslie (Sept., 2001, Mali and Ghana), Jeffrey Wilson, USDA-ARS Millet Pathologist/Breeder (Sept., 2001), Tom Crawford (Aug.-Sept., 2001 - Mali), and (March-April, 2002 - Ghana and Senegal). Other planned travel in October was cancelled due to the Sept. 11 terrorist tragedy.

Host country scientists travel included: Dr. Aboubacar Toure to U.S. for INTSORMIL Technical Committee Meetings, Nov., 2001 and April, 2002; to ASTA (American Seed Trade Association) Annual Corn and Sorghum Research Conference, Chicago December 5-7, 2001; to Lincoln, NE April, 2002, to Lubbock, TX, December 1-4, 2001 and May 10-15, 2002; to College Station, TX, May 8-9, 2002; and to Cornell University, May 5-7, 2002. Dr. Ibrahim Atokple to Lubbock, TX, August 13-September 19 for short term training in hybrid sorghum breeding and learning sorghum germplasm. Dr. Niamoye Diarisso to Quito, Equador, April, 2002, for a CGIAR system wide IPM meeting. Mr. Abdoul Waheb Toure to Montrieuil, France, Nov. 14-23, 2001. Mr. Kissima Traore, sorghum breeding technician at Cinzana, Mali, to Lubbock, TX, September 2 - October 6, 2001 for short term training in breeding and crossing.

Networking

An efficient sorghum and millet research and technology transfer network exists though the West African regional sorghum and millet networks, WCASRN and ROCAFREMI. The INTSORMIL/IER collaborative program is integrated on a regional basis. Technologies developed in Mali are transferable to most countries in West Africa particularly in the areas where head bugs, drought, and grain mold which are common. Exchange of elite germplasm with useful traits is ongoing among breeders in the region. The emerging interaction with NGO's, the University of Mali (IPR de Katibougou), farm organizations, and extension in conducting on-farm research and tests is a positive one that efficiently utilizes scarce resources and personnel. The program is using this approach to evaluate new improved breeding cultivars and other technologies in the West Africa Region. Efforts are underway to reinforce coordination of research programs and activities with other countries in West Africa. Collaborative INTSORMIL research was initiated in Ghana and Senegal in the 2001 season, and some initial efforts have been taken to tie some of this in with researchers and programs in Burkina Faso, Nigeria, and Niger.

The program has also interacted with ICRISAT, TROPSOILS, NOVARTIS, etc. There has been a long history of collaboration with ICRISAT in Mali especially in breeding, entomology, and weed science. The program has assembled, planted, increased and characterized the Mali Sorghum Collection in collaboration with USDA-ARS, ICRISAT, ORSTOM, CIRAD, and seed is in storage in Mali and has been introduced into the U.S. and grown out under quarantine. The seed increase and characterization were completed in 2001 and the complete set of data on the over 40 grain, glume, and plant characters was compiled and sent to the USDA/ARS for entry in the GRIN system. The development of a working group for active use is ongoing. After the seed is processed, complete sets will be sent, as appropriate to ICRISAT, ORSTOM, and Mali.

New Ghana and Senegal Collaboration

Plans to initiate INTSORMIL collaborative research in Ghana and Senegal began in November 2000, with arrangements to bring two scientists each from Ghana (Drs. S. Buah, Agronomist and I. Atokple, Sorghum Breeder) and Senegal (Ndiaga Cissé, Sorghum Breeder and Demba M'Baye, Pathologist) to Bamako to meet with Darrell Rosenow, Aboubacar Toure, and other key Malian IER scientists. Dr. Buah already had previously initiated a collaborative program in agronomy with Dr. J. Maranville. The discussions were all very fruitful and positive with three initial areas of collaboration among Malian, Ghana, and Senegal scientists agreed upon: 1) Sorghum Breeding with the establishment of a germplasm exchange program centering on a West African Regional Breeding Nursery to which all breeders would contribute new breeding germplasm or cultivars annually, and would be assembled and distributed by Dr. Toure in Mali; 2) Sorghum Pathology centered initially on a West African Disease Nursery to which all pathologists and breeders would contribute entries annually and would be assembled and distributed by M. Diourte in Mali; and 3) *Striga* research with initially a *Striga* nursery of known or suspected *Striga* resistant local cultivars and selected lines from Gebisa Ejeta evaluated at several sites. The lines will be assembled in Mali and distributed by Acar Toure. Also Dr. Ejeta will look at some of the sources for types of resistance involved. In addition, INTSORMIL scientists in the U.S. will provide breeding germplasm for midge resistance, drought resistance, grain mold resistance, other disease resistance, and elite sources fo worldwide germplasm for the new breeding programs in Ghana and Senegal. Requests were made by scientists in Ghana and Senegal for the future development of collaboration in millet breeding, entomology (head bugs and midge), cereal technology and utilization, and agronomy. Dr. Buah continued his collaborative activities in Ghana in 2001 based on already developed cooperation with Dr. Maranville.

Research Accomplishments - Summary

The most significant impact of INTSORMIL has been the strengthening of the IER both through staff training and research capacity building. Interdisciplinary and cooperative research in sorghum and millet which are in place at the IER are mainly due to INTSORMIL/IER collaborations. The multidisciplinary approach to solving technical problems have been promoted by the INTSORMIL, and is functioning well in Mali.

Breeding

From on-farm trials, the cultivar 97-SB-F5-DT-63 (N'Tenimissa*Tiemarfing) has been selected, seed saved, and grown by local farmers and named "Uassa" which mean 'satisfaction' in Bambara. Farmers like it over N'Tenimissa because of its whiter, higher quality grain.

Eight local photosensitive sorghum cultivars have been improved through mass selection and are grown by farmers on a significant area in Mali (CSM 388, CSM 219E, CSM 63E, Foulatiéba, Séguétana CZ, CMDT 45 , CMDT 39).

The white-seeded, tan-plant Guinea type breeding cultivar, N'tenimissa, was released. It's yield is equal to or slightly superior to local checks. It has good farmer acceptance regarding yield and food use. Flour from N'tenimissa is currently being marketed commercially (20% N'tenimissa and 80% wheat flour) in a cookie called déli'ken by the private company, G.A.M., in Bamako.

A local entrepreneur in Mali successfully produced over 11 tons of grain of the white, tan plant guinea cultivar, N'Tenimissa, under identity preserved (IP marketing procedures. This grain trader also developed a new market by packaging and selling one kilo bags of flour (Sorgha Phar) in Bamako markets, with a demand so strong he was having trouble keeping the product on the shelf.

Several white, tan plant true Guinea breeding lines were identified: 96-CZ-F4-99 (late maturity); 97-SB-F5-74-1, 97-SB-F5-74-2 (medium maturity); and 97-SB-F5-63, 97-SB-F5-64 (early maturity), all from the cross (N'ténimissa*Tiémarifing). They have been evaluated on-farm with promising results. They have somewhat superior grain quality and show less stem breakage than N'tenimissa.

Varieties of millet selected for the tallest expression of the D2 dwarfing complex (1.7 to 1.9 m) have given good performance in millet/legume intercropping studies.

Testing in Texas and Mali has demonstrated that the drought response in Mali is similar to the drought response in West Texas increasing probability of success in breeding for enhanced drought tolerance.

The Mali Sorghum Collection of indigenous cultivars from Mali was successfully grown in 1997, was characterized and seed increased and distributed. A small working collection has been identified. There was greater diversity in the collection than anticipated. Approximately one-third of the collection was grown in St. Croix in the spring of 2000 with seed increased and characterization completed. The remaining two-thirds was grown in a St. Croix quarantine growout in winter, 2000-2001, and seed increased and characterization completed. A tentative working collection was identified.

Entomology

The adverse effect of head bugs on the grain food quality of introduced sorghum across West Africa was first recognized and documented in Mali.

The INTSORMIL collaborative sorghum entomology research program in Mali has discovered the best source of genetic resistance to head bug (*Eurystylus marginatus*), a major constraint to the quality of grain sorghum in Mali, in an IER Malian developed cultivar, Malisor 84-7.

An easy, efficient technique for screening for head bug resistance using bagged vs. non-bagged heads has been developed and is used cooperatively by the breeders and the entomologists.

Observations indicate that head bug infestations in on-farm trials is much lower than in Station Nurseries. This means that sorghum with somewhat lower levels of head bug resistance may well work at the farm level, even though they may show significant damage under certain Station infestations.

Pathology

Grain yield increase of 20% can be obtained by treating millet seed with Apron plus.

Protection from head bugs will be a requirement for evaluation of grain mold resistance.

Long smut (*Tolyposporium ehrenbergii*) is severe in the drier regions of Mali. Anthracnose (*Collectostrichum graminicola*) is a very serious sorghum disease in Mali.

Studies were conducted on covered kernel smut (*Sphacelotheca sorghi*) by using traditional fungicides and the results showed that "Gon" (*Canavalia ensiloformis*) used in seed treatment had the same effects as Apron Plus 50DS and Oftanol.

Agronomy

INTSORMIL/IER research has demonstrated that millet or sorghum planted after peanut or cowpea results in 36-63% yield increases.

INTSORMIL collaborative research has shown an increase in pearl millet grain yield and biomass production due to previous cowpea crops and equivalent to the application of 30 to 40 kgha^{-1} N.

The joint INTSORMIL/TROPSOILS collaborative program has addressed soil chemical properties associated with nutrient deficiencies toxicities in sandy soils of the Cinzana Station. Some Durra varieties from Niger and northern Mali show tolerance to soil toxicity (Bagoba, Babadia Fara, and Gadiaba)

A method of screening large numbers of sorghum and millet lines for early generation and selection for seedling stage drought resistance using a charcoal pit has been adapted and is used.

Nitrogen use efficiency (NUE) of improved sorghum cultivars has been better than that of local cultivars at higher N rates, while local cultivars had better NUE at zero and very low N rates.

Without fertilizer application all tested cropping systems (including legume rotations) mine the soil of nutrients.

Crop rotation with cowpea and leaving crop residues in the field (either incorporated or on the surface) increases the sustainability and productivity of pearl millet cropping systems.

Weed Science

Several *Striga* resistant lines from Purdue evaluated in Mali showed good *Striga* resistance, but had inferior grain quality compared to local cultivars.

Striga resistance using lab screening to *Striga asiatica* in the U.S. works under field conditions to *S. hermonthica* in Mali.

New sources of resistance to *Striga* were identified: Séguétana CZ, CMDT 45, CMDT 30, CMDT 39.

Grain Quality and Utilization

Mini tests for evaluating milling and tô properties were developed and currently are used in the laboratory. Sorghum with hard endosperm and thick pericarps was definitely required for efficient traditional hand pounding. The size and shape of the pearl millet kernels affects dehulling properties significantly.

Head bugs damage reduced sorghum milling yields and produced tô with unacceptable texture and keeping properties.

Parboiling can convert sorghum and millet into acceptable products. It improves dehulling yieds, especially for soft grains. The cooked milled products can be eaten like rice.

The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children. This technology has been transferred to many villages especially in the Cinzana area.

Mileg, a weaning food using primarily millet flour has been developed by private entrerprise and marketed in stores in the Bamako area. The product was developed using technology developed in the IER Cereal Technology laboratory.

New white-seeded, tan-plant, tan-glume guinea-type breeding cultivars, have good potential for use in developing new high quality, value added food products. They posses excellent guinea traits and yield potential.

Déli'ken, a cookie using 20% N'Ténimissa flour and 80% wheat flour has been developed by private entrerprise GAM and marketed in stores in Mali.

A new market for N'Tenimissa flour has been developed with the successful marketing of 1 kg bags of N'Tenimissa flour in Bamako by a local entrepreneur.

Economics/Marketing

In Mali, a local entrepreneur successfully produced grain from the white-seeded, tan-plant Guinea cultivar, N'Tenimissa, under identity preserved (IP) marketing procedures, involving 38 ha and 50 farms in 4 villages. From 38 tons harvested, over ll tons were sold to the grain trader. When the demand for sorghum flour by GAM for cookies dropped due to reduced tariff on wheat imports, a new market for the N'Tenimissa flour was developed with the marketing of one kilo bags of N'Tenimissa flour (Sorgho Phar) in markets in Bamako. Demand was so strong, there were problems keeping the product on the shelf.

An economics study on the benefits of new technology in Mali suggests that new technology in the traditional cereals of sorghum and pearl millet would provide a greater increase in benefits compared to new technology introduction in the new cereals, maize and rice.

The domestic cereal economy has been helped by devaluation with the increased relative price of sorghum and millet to rice. A future devaluation is expected to result in much more substitution of traditional cereals now that there is only a minimal rice tariff.

In spite of substantial introduction of new sorghum and millet cultivars, there has been minimum aggregate impact on yields. Only where inorganic fertilizers and improved water retention or irrigation were combined with new cultivars, have there been large yield increases. Given the low soil fertility and irregular rainfall in semi-arid regions, both increased water availability and higher levels of principal nutrients will be necessary for substantial yield increases. Improved cultivars alone are unlikely to have a significant effect upon yield.

The lack of a consistent supply of high quality sorghum and millet grain is the major constraint limiting value-added grain processing.

Lack of farm credit for millet and sorghum, compared to cotton and maize, discourages adoption by farmers of improved millet and sorghum technology, especially in the Sudano-Guinean (higher rainfall) zone.

West Africa – Eastern Region

Bruce Hamaker
Purdue University

Coordinators

Issoufou Kapran, INRAN/INTSORMIL Coordinator, B.P. 429, Niamey, Niger
Bruce Hamaker, Regional Coordinator, Food Science Department, Purdue University, West Lafayette, IN 47907
Katy Ibrahim, Administrative Assistant, International Programs in Agriculture, Purdue University, West Lafayette, IN 47907

Collaborative Program

The recently regionalized INTSORMIL program in the eastern region of West Africa includes a long-standing collaborative research effort in Niger, and newer and smaller programs in Burkina Faso and Nigeria. All are multidisciplinary efforts that focus on sorghum and millet improvement in the region, however Niger has the only full range of research activities spanning production agriculture-related projects, utilization, and economics. ICRISAT has been an institutional collaborator in the region, as well as the regional millet and sorghum networks of ROCEFREMI and ROCARS. Research plans are developed between host country PI's and U.S. INTSORMIL collaborators. A first regional meeting was held in Niamey in March 2000 with the aim of sharing research results and strategizing to meet the needs of the region. In this last year, a meeting was not held in lieu of the All-PI Conference in Addis Ababa in November 2002. However, in future years there will be a resumption of regional PI meetings.

List of Disciplines and PI Collaborators

Genetic Enhancement – Sorghum and Millet

Sorghum: INRAN, Niger - I. Kapran; KSU - M. Tuinstra, Purdue – G. Ejeta, and L. House (ret.)

Nigeria - P. Marley; TAM – D. Rosenow

Burkina Faso – A. Neya; TAM – D. Rosenow

Millet: INRAN, Niger – J. Gonda; ARS – W. Hanna

Lake Chad Research Institute, Nigeria – I. Angarawai

Sustainable Plant Protection Systems

Entomology: INRAN, Niger - H. Kadi Kadi; TAM – B. Pendleton, F. Gilstrap

Plant Pathology: INRAN, Niger – A. Kollo (on leave to Texas A&M University/ARS)

Sustainable Crop Production Systems

Agronomy: INRAN, Niger – S. Sirifi; UNL – S. Mason

INERA, Burkina Faso - J.B. Taonda; UNL – S. Mason

Economics: INRAN, Niger – T. Abdoulaye; PU – J. Sanders

Utilization and Marketing

Utilization: INRAN, Niger – K. Saley, M. Moussa; PU – B. Hamaker

University of Maiduguri, Nigeria – I. Nkama; PU – B. Hamaker

Marketing: UI – C. Nelson

Sorghum/Millet Constraints Researched

Sorghum and pearl millet are staple food crops of Niger, Burkina Faso, and northern Nigeria. In Niger, sorghum acreage increased from less than half a million hectares in 1961 to more than two million hectares in 2000. Grain yield declined from 0.6 t/ha to 0.2 t/ha during the same period. Sorghum and millet production in the eastern Sahelian region of West Africa is severely limited by biotic and abiotic stresses including drought, poor soils, insect pests (especially midge and headbugs), and diseases including long smut and *Striga*. In the 1998 strategic plan for sorghum and millet prepared by the Institut National de Recherches Agronomiques du Niger (INRAN), emphasis was placed on technology transfer, development of varieties with better yield stability, and plant protection. Improved utilization of these cereals, such as through commercial processing to products or animal feed use, is also key to expanding demand and markets, as well as generating income at the entrepreneurial level.

INTSORMIL's support for sorghum and millet improvement has been significant in terms of human resource enhancement and vision for technologies that can be transferred and adopted by farmers and other end-users. For example, sorghum and millet breeders and food technologists work together to demonstrate feasibility of the use of improved seeds to increase food production, diversify uses for local consumers, and stimulate entrepreneurial businesses.

Institution Building

Office supplies including a typewriter, binding machine and shredder, as well as research expandable supplies (pollinating bags) were purchased for field work in Niger. In addition, a laptop and software were purchased for the same program.

Tahirou Abdoulaye completed his Ph.D. studies at Purdue under the supervision of John Sanders. He will be remaining at Purdue University until December 2002 to work with Dr. Sanders on a biotechnology potential and constraints study in West Africa, and developing a millet and sorghum marketing project in collaboration with ROCAFREMI. These two activities will involve traveling to Niger, Burkina Faso, Senegal, and Mali.

Dr. Abdourahmane Kollo continues his position as visiting scientist in the USDA/ARS plant pathology laboratory at Texas A&M.

Dr. Issoufou Kapran, INRAN/INTSORMIL host country coordinator made two trips to the U.S. during FY2001/2202. He spent approximately 3 weeks on campus in October to evaluate the Purdue sorghum nursery and make selections for use by INRAN in Niger. He also traveled to Nebraska to participate in the Technical Committee meetings and the All-PI organizational meeting in late April early May 2002.

Research Progress

Niger

Sorghum Breeding and Seed Production
I. Kapran, G. Ejeta, and L. R. House (consultant)

Major constraints facing sorghum production in Niger include drought, poor soils, insect pests, diseases, and *Striga*. INRAN has a strategic plan that recognizes the need to focus on yield improvement as a means to achieve higher sorghum production. Priority areas include (1) collaborative on-farm evaluation of existing improved varieties and hybrids; (2) development of new varieties possessing high and stable yields; and (3) pest management.

In Year 2001, activities focused on breeding nurseries and trials, and hybrid seed production. Field trials and nurseries were organized to identify the best materials to go for release as cultivars, or as breeding lines for further improvement. INTSORMIL PIs at Purdue University (Ejeta) and Texas A&M University (Rosenow) supplied germplasm; other partners were the regional sorghum network (ROCARS), and NARS in the West Africa region (Mali, Nigeria, Burkina Faso). It should be stressed that the INRAN/INTSORMIL joint breeding program has a strong orientation for collaboration with the INRAN Seed Unit (U.S.) and the INRAN Food Technology Laboratory (LTA).

The objective is to identify highly productive and well adapted hybrids that will be released for commercial production. New hybrids and lines were evaluated for early maturity, grain quality, grain yield and overall adaptation at the following INRAN locations: Konni, Tahoua, Bengou, Kollo Lossa, and Tillabery. Planting was done between June 15 (Lossa) and July 23 (Konni). Common problems were high damages by midge and some long smut infestation.

The following nurseries were installed:

A1. Identification of A-lines with good adaptation and stability in seed production to replace TX623A. TX623A, the female parent of NAD-1 hybrid, while being an excellent combiner, has many problems of adaptation (susceptibility to long smut disease, *Striga*, midge) and has poor seed quality (often translating into poor germination), all of which complicate seed production; TX623A is also of a different maturity than MR732, the male parent of NAD-1, thus staggered planting is required for seed production, which is not the easiest way for on-farm production. Based on the above, a nursery was planted with two planting dates at the Lossa station (June 15 with irrigation; and july 15 rainfed) to collect data on flowering, and susceptibility to long smut and grain mold. As for the previous year, the following female parents were selected as the most adapted, and cover a wide range of maturities: P9504, P9511, P9512, P9521, P9526, AHF8, 223A.

A2. Field testing of experimental hybrids. More than 1300 hybrids were tested (Table 1). This wide array of combinations is designed to provide new hybrids that not only have agronomic performance equal to or better than NAD-1 check, but also better grain quality and wider adaptation (especially early hybrids), in the framework of parents with the same maturity. Yields were generally low, but there were strong indications of entries that merit further testing. Results of selected trials are shown in Table 2.

Hybrids with female 223A are highly productive and possess good evident grain quality, although not earlier maturing than NAD-1. A subset of hybrids in the observation nursery was sent to the INRAN Food Technology Lab for analyses (see report below).

Earliness was clearly expressed in IS10360A hybrids, however their yield was not as good as that of the check (MM) and their grain quality was poor.

Table 1. Experimental hybrids tested, Niger 2001

Hybrid observation nursery	767	Intercrosses between 60 A-lnes (PU, TAMU, UNL) and 74 R lines (INRAN, ICRISAT, ROCARS, PU, TAMU)	Lossa, Kollo	Only hybrids between parents of same maturity group
Preliminary hybrid trial	97	Intercrosses between selected A&R lines	Kollo, Lossa, Bengou, Maradi	
Advanced hybrid trial	8	Intercrosses between most elite A&R lines	Kollo, Lossa, Bengou, Konni, Maradi	
idctlparPU Hybrid observation nursery	400	Crosses of dryland adapted lines	Maradi	
PU early maturing hybrids	33	Single female parent=IS10360A	Maradi	
PU advanced hybrid trial	26	Selected female and male parents	Kollo, Lossa, Maradi	

Table 2. Yield averages in selected hybrid trials

Trial	Trial mean (kg ha^{-1})	Best yield (kg ha^{-1})	Check mean (kg ha^{-1})
Preliminary (Maradi)	476	2250 (223AxR1/ST9007)	666 (MM)
Advanced (Kollo)	1097	1550 (223AxMR732)	1122 (MM)
Early maturing (Maradi)	714	1667 (MM)	1667 (MM)

Hybrid seed production: This activity has received higher priority than variety trials, in the context of the existence of a seed unit at INRAN. As noted before, the seed unit is modeled after NAD-1 seed activities designed and implemented thus far under INRAN/INTSORMIL collaboration. Other partners include the IFAD/INRAN technology transfer project, the IFAD/Tillabery project, and the WINROCK-ONFARM project.

The objectives of the seed unit are:

- Management of breeder and foundation seed of cultivars in high demand (millet, sorghum, cowpea, groundnuts, onions);
- Contribution to the initiation of a modern seed industry in Niger.

The following activities were successfully conducted:

Parental seed production (on-station): Female parents TX623A and 223A were each increased at Lossa station (Table 3). This location has been selected over the years for parental seed production because of isolation, availability of irrigation, dry air, no *Striga*, midge, or grain mold (or negligible levels).

Hybrid seed production: NAD-1 and F1-223 hybrids were produced at the Tillabery station (Table 3). The quantities of hybrid seed were still low, due to limited funding and land availability with INRAN. This activity will need major financial input to take off. All seeds produced were cleaned and stored at the Lossa national seed farm for optimum storage quality. In addition to INTSORMIL, INRAN through its seed unit, and the regional sorghum network (ROCARS) supported this activity.

Table 3. Elite sorghum varieties and hybrids increased, INRAN/INTSORMIL 2001

Identification	Seed produced (kg)
NAD-1 hybrid (released)	1437
F1-223 hybrid (advanced)	677
TX623A (female)	292
223A (female)	273
SEPON82 OPV (released)	180
MM landrace (released)	1652
Total	4511

On farm hybrid seed production and farmer training: Farmer cooperatives at Tiaguirire (WINROCK) and Gidan Iddar (IFAD/INRAN) also undertook hybrid seed production. At both locations there was continuous monitoring of procedures to help farmers produce good quality seeds. Gidan Iddar farmers and technicians also received formal training using the manual for hybrid seed production in Niger (House/Kapran) that was translated into local languages with support from Winrock International. In addition regular on-hands training sessions will be organized for farmers during seed production period.

In addition to the above, a trial was initiated in collaboration with INRAN and INTSORMIL agronomists Dr. S. Sirifi and Dr. S. Mason. This is in response to our search for the best management options to optimize hybrid seed production. Initial observations indicate that high density planting (80 cm x 20 cm) and high fertilizer rate (200 kg ha^{-1} of urea) may be conducive to excellent nick and hybrid seed production.

Sorghum/Millet Quality and Utilization

K. Saley, M. Moussa, M. Oumarou, I. Kapran, A. Aboubacar, and B. Hamaker

Primary Objective

- The overall objective of this project is to initiate processing and commercialization of value added sorghum and millet products with particular emphasis on utilization of locally and regionally fabricated food processing equipments.

Specific Objectives

- Optimize sorghum couscous and associated products.
- Complete the 1st and 2nd phase of the marketing study in order to learn about the acceptability and the market potential of the processed NAD1 couscous.
- Optimize the processing equipment
- Transfer of the technology to beneficiaries.

In the past year, the second phase of a marketing survey was conducted by introducing the processed NAD1 sorghum couscous into selected market segments. About 600 kg of couscous was distributed in nine selected stores. A short questionnaire was given by sales agents to consumers who purchased the couscous in those sales stores, and information related to price, rate of sales and packaging quality was collected from buyers.

Table (4) indicates the production capacity of the pilot unit. The current capacity may be sufficient for processors who want to start processing and commercialization of sorghum / millets products.

Regarding the 2nd phase (market potential) of the sorghum couscous, impressive results were obtained this year.

Dissemination of Technologies

The national forum on sorghum/millet organized by INRAN, Sept., 2001

The world food day celebration, Oct 15, 2001, Niamey

The annual workshop organized by Africare-USAID, Niger Oct, 2001

The annual meeting of ROCARS, Nov. 2001, Burkina Faso

The annual meeting of FIDA-ARSAS, Feb. 4, 2002, Maradi, Niger

The workers day celebration, may 1, 2002, Niamey

A team of private processors was trained to process sorghum/ millet products at the pilot unit/ cereal lab/INRAN. From April, 2, 2002 to May, 2, 2002.

Recently, 1 metric ton of NAD1 grain was processed to flour and couscous with financial support from the sorghum network, ROCARS. Information related to consumer acceptability and responsiveness to price of sorghum NAD1 couscous and flour will be collected.

Entomology

H. Kadi Kadi and I. Kapran

In Niger, insects feeding at the different developmental stages cause low yield and grain quality. The most important insect pest of sorghum is the sorghum midge, *Stenodiplosis sorghicola* (Coquillet) causing damage to flowering panicles. Midge is most damaging to late maturing varieties with a long vegetative phase. Such varieties sometimes suffer a non-formation of more than half their seeds.

Table 4. Equipment and throughput involved in couscous processing.

Equipments	Processes	Throughput
Electrical decorticator (abrasif type) 1400 r.P.m; 4 kw = power (URPATA, Senegal)	Dry decortication	150-250 (kg/h)
Electrical Hammer mill 3000 r.P.m ; 5,5-7,5 kw = power (URPATA, Senegal)	Dry milling fine, medium and coarse flour (0,5; 0,7; 1 mm)	200-300 (kg/h)
Sieving (manual type)	0,2-0,5 mm) particle size	100 (kg/h)
Food mixer 650 watt (Kendwood)	Hydration : flour + water	30 (kg/h)
Agglomerator-rouleur 16;22; and 36 r.P.m., 0,25 kw = power (Montpellier –France)	1-2 mm particle size couscous and associated products	40 (kg/h)
Couscoussier (Nigeral, Niger)	Steaming with butane gas cooker	10-20 (kg/h)
Solar dryer 32 m² / aluminum / natural convection / insulation : Solar Radiation	The couscous is spread in thin layer form in the drying chamber	40 kg/24 h
Packaging (Birnberg machinery) 210 watt		30-50 packets/h
Grain destoner (electrical) URPATA Sahel, Senegal		200-300 (kg/h)

Research studies on biology and population dynamics of sorghum midge and the application of the integrated pest management principles (planting dates, cultural techniques, host plant resistance and chemical control) have helped to determine some promising resistant varieties that can sustain sorghum midge damage. In Niger, the adults of *Stenodiplosi* spp. began to appear in the field in two generations between mid-September and early-October (Maïga 1980 and Samir 1984).

- The major objective of the entomology project has been to determine the sorghum lines resistant to sorghum midge. After two years of screening some sorghum materials introduced from Texas by the INRAN breeder, the varieties, TAM 2566, TX 2782, TX 2755, and TX 2890 were identified as resistant to sorghum midge (Kadi Kadi 1994). New resistant sorghum lines must also have, through crossing with high performing varieties, agronomically acceptable characters.

In the 2001 cropping season, the results obtained from single seed descent sorghum lines with midge resistance showed no significant differences between the lines for damaged spikelets ($F = 0.89$, $P < 0.001$) at the 1st planting date. Four sorghum lines (99 SSD F9-3, 99 SSD F9-24, 99 SSD F-32 and IRAT 204 had highest damaged spikelets (50-60%). The percentages of grain loss recorded on these lines were 20-50%. At the 2nd planting date, most of the sorghum lines tested have <10% damaged spikelets. Highest midge damages were recorded at the 1nd planting date because the midge outbreaks were favored by the coincidence with the sorghum flowering stage. Sorghum lines 99 SSD F9-18, 99 SSD F9-21, 99 SSD F9-29, 99 SSD F9-33, 99 SSD F9-35, ICSV 745 were found to be resistant to midge. These lines had the lowest (12-28%) grain loss even though some had highly damaged spikelets. The results confirmed that, after three years of screening, lines ICSV745, 99 SSD F9-21, 99 SSD F-33 and 99 SSD F9-35 are resistant to sorghum midge.

A new process of developing sorghum lines resistant to midge by the single seed descent procedure started in 2000: two midge resistant varieties (ICSV 745 and ICSV 88032) were crossed with 4 varieties (MM, IRAT 204, MR 732, ATX 623). F_1 populations of these differents crosses were obtained. The most promising F_1 populations of ATX 623 x ICSV 745 and ATX 623 x ICSV 88032 were advanced to F_2 during the 2001 cropping season. These populations are being advanced to F_3 generation during the 2002 cropping season. This will help to develop new sorghum lines resistant to midge that will produce high yield even under high midge infestation level. These lines will have higher performance, commercially acceptability, and could be used to develop new sorghum lines.

Perspective. During the past year, progress was made to start some collaborative research activities with Dr. Bonnie Pendleton who was awarded an INTSORMIL CRSP project "Sustainable management of insect pests in West Africa and the United States". Collaborative research activites on sorghum will be oriented to: 1) identify sorghum lines with stable resistance against sorghum midge, 2) determine if variation in the flowering of sorghum lines affect sorghum midge incidence and day-to-day variation in midge population abundance, 3) develop new sorghum lines resistant to sorghum midge through Single Seed Descent procedure, 4) exchange promising materials with other scientists within the region or the USA and 5) deliver and adopt the new lines or varieties at the farmers level.

On millet, collaborative research activities will focus on assessing the abundance and causes of mortality of millet head miner under field conditions to better understand natural enemy-host interactions. Specific objectives of the research activities will be to: 1) verify methodology for sampling and manipulation of millet head miner populations and its natural enemies and 2) conduct field cage exclusion studies on natural enemies attacking millet head miner on millet.

Millet Breeding
J. Gonda and W. Hanna

Millet hybrids introduced from Tifton, Georgia were compared to local checks CIVT and CT6. In general, hybrids were earlier maturing have higher tillering capacity and yield compared to CIVT and CT6. Hybrid WA28 was the earliest maturing with a 50% heading cycle of 61 dap and 50% blooming cycle of 70 to 71 dap, but was significantly different only from the checks CIVT and CT6 and hybrid Wa23. Hybrids Wa27 and 28 had significantly higher tillering capacity (panicle #/ha) with 47,481 heads per ha., but were only significantly different from the local checks CIVT and CT6 , with 29,988 heads per hectare and from hybrids Wa11 with 29,155 heads per hectare. Hybrid Wa11 had the lowest tillering capacity with 29,155 heads per hectare.

One of the potential problems of these hybrids was head length. There were highly significant differences between hybrids and in between hybrids and local checks for panicle length. Local checks had the longest panicles at 61 and 51 cm, and they differed significantly from all the tested hybrids which had panicle lengths of 21 to 37 cm. All the hybrids were short panicle length genotypes.

There was a significant difference between hybrids, and between hybrids and local checks for yield. Hybrid Wa25 yielded significantly better with 1,104 kg per hectare, though differed significantly only from hybrids Wa15 (666 kg ha^{-1}), Wa19(636 kg ha^{-1}) ,Wa29 (583 kg ha^{-1}) and Wa30 (437 kg ha^{-1}). Good yielding hybrids such as Wa25, 24 and Wa16 (yielding from 1104 to 1020 kg ha^{-1}) show promise for future breeding activities.

Socioeconomics
T. Abdoulaye and J. Sanders

T. Abdoulaye of INRAN/DECOR completed his Ph.D. in agricultural economics at Purdue University. His Dissertation, “Farm Level Analysis of Agricultural Technological change: Inorganic Fertilizer Use on Dryland in Western Niger” was funded through INTSORMIL with field work partially funded by the Natural Resource Management Program of ICRISAT and INRAN.

Despite the harsh economic and physical environment, survey results indicate that farmers from the Fakara region are investing in micro and moderate doses of inorganic fertilizer in order to increase their agricultural production and to respond to soil nutrient depletion. This change in their farming practices has been facilitated by their exposure to the effects of inorganic fertilizer through trials and demonstrations according to the econometric results. There is apparently a path of fertilizer use by farmers with different factors becoming critical along the way. Once the traditional soil fertility maintenance system breaks down, due to population pressure, per capita crop production declines, which forces farmers to look for alternatives. They generally start by using manure. When manure potential is exhausted and conditions are favorable, they start using micro-doses of inorganic fertilizer along with the manure. Micro-doses consist of using small doses of inorganic fertilizer applied directly into the hole where the seeds are planted. This method makes efficient use of small quantities of inorganic fertilizer. Moreover because the quantities applied are small, liquidity for input purchase is not a major issue. Farmers gradually increase doses of inorganic fertilizer to eventually move to moderate doses.

Results indicate that in regions where there have been demonstration trials, farmers are using various kinds and techniques of fertilization. There is some statistical support for our hypothesis that the principal factor determining the use of micro-doses of inorganic fertilizer are profitability (millet relative price) and the need for farmers to see it used in the field. Farmer’s ability to finance input purchase becomes a factor for moderate dosage level. To get the fertilization process started, the main factors appear to be profitability and farmers being comfortable with the technologies through demonstrations and trials. Wealthier farmers were more likely to use fertilizer but the separate liquidity variable for availability of capital had little effect on its use. The wealth of the household becomes an issue when the farmer wants to shift to moderate doses of inorganic fertilizer. Because the moderate dosage technologies require a higher investment, the farmer needs to be wealthy enough to afford the cost of the investment. With this highly divisible input farmers could and did begin utilization on very small levels and then shifted to moderate fertilization if they were wealthy enough to wait for the post harvest price recovery.

Introduction of new technologies (including higher and better quality inorganic fertilization and new cultivars) will lead to 30% increase in household expected income as well as an increase in farmers’ coping ability because of increased crop production. The fertilization process can be accelerated if policy makers recognize the importance of farmer profitability for the intensification of agricultural production. This increase in fertilization leads to higher production and expected farm income is increased by an additional 16% compared to the solution with new technologies alone. Changing the current policy aimed at low food prices by maintaining low prices paid to farmers, would be a significant step toward reducing soil degradation in Niger. Food prices need to give signals to farmers to increase current capital expenditures because intensification will be profitable for them. In the long term technological change enables falling per unit output costs so prices can fall moderately with both farmers and consumers still benefiting.

Agronomic Studies for Producing
Hybrid Sorghum Seed
S. Sirifi, I. Kapran, S. Mason

During the 2001 cropping season, agronomic studies on pearl millet and sorghum were undertaken in Niger. On pearl millet, two experiments were conducted: one on microdose application and the other on population hybrid . The microdose experiment was conducted on-station and on-farm at Kalapaté station and region located at about 120 km from Niamey. The population hybrid study was done in N’Dounga and Kallapaté stations. Work on sorghum concerns trials on density x fertilization (nitrogen or phosphorus) in hybrid production. Trials were installed in Kollo, Maradi and Lossa stations. Due to poor growing conditions, sorghum data is not included.

Pearl Millet Microdose Study. This is a regional INTSORMIL-funded study including Niger, Burkina Fasso and Mali. The objective of the study was to find out the best combination of microdose, nitrogen (N) and phosphorus (P) rates for millet production in the region. The microdose study consisted of on-station and on-farm trials. The on-station trial was installed on sandy sol in a fallow area with an average annual rain of 400 to 500 mm. It had eight treatments which were: a check (T1), microdose (T2), microdose + 20 units / ha of P (T3), microdose + 40 units / ha of P (T4), microdose + 30 units / ha of N (T5), microdose + 60 units /ha of N (T6), microdose + 20 units / ha of P + 30 units / ha of N (T7), and microdose + 40 units / ha of P + 60 units / ha of N (T8). The on-farm trial had three treatments only (T1, T2, T3) and was conducted in seven villages surrounding Kalapaté station on a distance of about 10 km apart. The microdose was the content of a coca cola bottle cup of an NPK fertilizer that was placed with seeds in hills at planting. The source of fertilizer used for the microdose was 15 15 15. For both experiments, an improved millet genotype called Zatib was used. A randomized complete block design was used with four replications. Before planting, soil samples had been taken in each plot for analysis.

In the on-station trial, grain yields varied between 455.7 kg ha^{-1} for the microdose + 40 P units/ha treatment (T 4), and 976.6 kg $ha^{-1}$for the microdose + 60 N units/ha treatment (T6) and microdose + 40 P units/ ha + 60 N units/ha (T8). The same tendency was observed for the other variables such as the biomass yield, the number of heads per meter square and the harvest index. In the on-farm trials grain and biomass production was much lower than in the on-station's. Grain yields of T1, T2 and T3 were 307.84, 326.33, and 460.78 kg ha^{-1}, respectively in on-farm trials, while they were 520.8, 642.9 and 765.0kg ha^{-1}, respectively, in on-station trial. In conclusion, two observations could be made from the microdose study on pearl millet. First, the use of microdose alone tended to improve seed germination and plant growth at early stage. Second, application of N up to 60 units tended to increase grain and biomass yield, but phosphorus application seemed not to have any effect on grain and biomass production.

*Pearl Millet Population Hybrid Study***.** A factorial experiment combining genotypes and environment was conducted at two INRAN research stations : N'Dounga and Kalapaté located at around 20 and 120 km from Niamey, respectively. Two factors was studied in this experiment – 1) genotypes which were composed of an improved local variety called Zatib, and a population hybrid named WA 13 (Georgia) from the U.S., and 2) environment which consisted of a poor cropping condition and a rich one. In the poor environment, both genotypes were cultivated with no fertilizer and planted at 0.80 m x 0.80 m. In the rich environment, the two genotypes were grown with fertilization (30 kg ha^{-1} of N + 20 kg ha^{-1} of P) and planted at 0.80 m x 0.40 m. The main objective of the study was to determine the performance of the population hybrid of pearl millet compared to the locally improved millet genotypes and see if pearl millet hybrids can be adopted by farmers from Niger.

Results did not show any interaction between genotype and environment for all variables in the two study sites. Nevertheless, main effect of genotype and environment indicated some significative differences among the two varieties and the two environments. On the main effect basis, yields from the local millet genotype (Zatib) were twice the amount as those from the population hybrid WA 13 (Georgia) in both localities. At Kalapaté station for example, grain yield of the local variety was 502.93 kg ha^{-1}, while that of the population hybrid was 201.17 kg ha^{-1} (table 6). Grain and biomass yields were greater in the rich environment than in the poor one (table 7). They were 485.35 against 218.75 kg ha^{-1} at Kalapaté and 367.19 against 283.20 kg ha^{-1} at N'Dounga for the rich and poor environments, respectivily. Production of the improved variety and the population hybrid was low eventhough the local millet perfomed much better than the population hybrid. Reasons for the poor performance of millet in this study were diverse, although insects, diseases, striga, soil poverty and drought were the main cause of this failure. For the population hybrid, seed quality might be another reason of its bad performance compared to Zatib, as its germination and stands were very poor.

Nigeria

Pearl Millet Hybrid Evaluations
I. Angarawai, W.B. Ndahi, I. Ezeaku

Multilocational Pearl Millet Hybrid Evaluation. Previous evaluation by Lake Chad Research Institute (LCRI) and ICRISAT have indicated that millet hybrids, based on male-sterile lines, are high yielding, disease resistant and tolerant to environmental stress. The present trials were carried out to evaluate these hybrid lines for yield and early maturing attributes across the millet growing zones of Nigeria. The trial was made up of 12 entries consisting of 10 hybrids, selected from Advance I and II hybrid trial of 2000 season, improved and local checks. The trial was planted in six locations; Maiduguri, Gashua, Kano, Katsina, Gosau and B/Kudu in Northern Nigeria. In each location, the experimental design was RCBD. Each treatment was replicated three times in plot size of 4.5 x 5 metre square. Data were recorded from 4 middle rows for days to 50% flower, grain yield, plant height, panicle length, downy mildew incidence and *Striga* score.

There were significant differences among the hybrid lines for days to 50% flowering and grain yield. Grain yield ranged from 2110 – 2346 kg ha^{-1}, with LCIC MH99=10 given the highest yield of 2346kg/ha. Days to 50% flowering ranged from 53-62 days in which hybrid LCIC MH99-25 was the earliest to flower. Downy mildew incidence was generally very low. In general, there is great potential in the hybrids for higher yields and earliness as indicated at Gosau with average yield of 3552 kg ha^{-1}.

Evaluation of Top cross Pearl Millet Hybrids. Some millet top cross hybrids obtained from the Tifton Experiment Station, U.S.A. under the collaborative arrangement between LCRI and INTSORMIL were evaluated in Maiduguri, during the 2001 cropping season. The main objective was to evaluate the performance of these hybrids their adaptability, stability, resistance to Downy Mildew, *Striga* resistance and grain yield. The trial was planted at the LCRI Experimental Station at Maiduguri. A total of 27 entries consisting of 23 top cross hybrids, 2 open pollinated and 2 checks were planted out in a RCBD experimental design with 3 replications. Planting was done on 29/06/2001 into plots made up of four rows, 75cm apart at an inter-row spacing of 50cm. Fertilizer was applied at the recommended rate of NPK 60:30:30kg/ha. The plots were hoe-weeded at 4 and 8 WAS.

There were significant differences among the hybrids for days to bloom, plant height, panicle length, downy mildew incidence and severity, and grain yield. It was generally observed that all hybrids line with SOSAT-C88 as female parent gave high grain yields, ranging from 1978-2155kg/ha. This shows that SOSAT-C88 can be exploited as a female parent, being a good general combiner for yield, medium maturing, average height, medium panicle length and lower downy mildew and *Striga* incidences.

Millet Utilization
I. Nkama

The major sorghum and millet production and utilization constraints include lack of improved millet varieties and lack of adoption of new production and utilization technologies by farmers and processors. An important use of sorghum and millet food in Nigeria is in the preparation of tuwo, kunu, fura, ogi, adaiey, masa, sinasiri, and dakuwa. Grain and flour properties that may contribute to the production of acceptable food products need to be defined. Also, improvement of traditional food products and revolutionary change of sorghum and millet to new shelf stable foods and industrial products is needed to encourage increased production of grain. Sorghum has faired better than millet in Nigeria because additional industrial uses are now available in areas of bear brewing, malt drinks, biscuits, and animal feeds.

Research Approach and Project Output

Millet grain samples grown by Lake Chad Research Institute (LCRI), Maiduguri, and local cultivars were analyzed for physical, chemical, rheological, and sensory properties. Various food products (weaning foods, tuwo, ogi (akamu), ndaley, fura, kunu, and dakuwa) were prepared to test the quality of the different grain samples.

Grain and Food Quality

Eleven multilocational pearl millet hybrid lines and one farmers' local grown by LCRI were evaluated for their physical, chemical, and sensory attributes. There were variations in the 1000 kernel weight (8.9 – 10.96 g), 1000 kernel volume (5.5 – 6.85 mg), density (1.05 – 1.63 g/ml), and germination percentage (85.7 – 97%). Also, the proximate composition varied considerably with the exception of crude fiber. Protein ranged from 10.6 – 13.8%, fat 4.1 – 6.8%, ash 1.3 – 1.8%, and crude fiber 2.0 – 2.4%. Protein fat, and ash content of all the hybrids ranged within the normal values for pearl millet and also in comparison with farmers' local. Preliminary studies on the acceptability of these hybrids for the preparation of kunu, zaki, and ogi showed that all the hybrid lines can be used to produce acceptable products. These hybrids can be considered as good materials for food processing.

Studies on Tuwon Tsari Flours

Tuwo is a thick porridge which is prepared from rice, maize, sorghum, or millet depending on taste, cost of grain, geographical location, and availability of grain. Tuwo is a common staple food item for about 57 million people living in the northern part of Nigeria. Tuwon tsari is a variation of normal tuwo prepared specifically from pearl millet. During its preparation, the grain is dehulled, steeped in acid water prepared from lime juice or tamarind pulp extract or kadel (steep liquor from previous fermentation for 2 to 3 days, sun-dried and ground into flour). The process of fermentation removes the colored pigment. The flour is cooked into a thick gruel before serving.

During the production of the tsari flour from 4 different pearl millet cultivars (Ex-Borno, GB8735, SOSAT-C88, and Zango), we observed that protein content decreased on an average of 24.5%, fat by 24.8%, and ash by 70.6%. There were no significant differences in the amount of protein recovered among the 4 cultivars, but recovery of fat and ash were significantly different among cultivars. *In vitro* carbohydrate digestibility of the native grain was low (20.4%). On processing, this increased to 71.5%. The *in vitro* protein digestibility also increased from 47.9% in the native grain to 54.8% in the tsari flour. Phytic acid content of the pearl millet samples decreased by 72% in the tsari flours and this resulted in the increase in mineral availability in all samples by 20% for calcium, 13% for copper, and 30% for phosphorous.

All tsari flour samples (6% w/w) had similar hot past viscosities (mean 35,840 centipoise). The peak viscosities were also similar, although tsari flour from Zango millet gave slightly lower peak viscosity. Tsari flour samples had a fairly high set back value which indicates that the cultivars would give good stiff porridges that are normally consumed with fingers. Sensory evaluation studies revealed significant differences in color, flavor, taste, texture, and overall acceptability of the tsari flour samples from the 4 cultivars. Tuwon tsari from Zango (a popular local millet grown in northwestern Nigeria) and SOSAT-C88 (improved cultivar released in 1999 by LCRI) received the highest scores. No sample was rated below average in all the attributes considered. The lowest average score was 6.6 on a 9 point hedonic scale. Studies in the Department of Science and Technology Laboratory at University of Maiduguri indicate that the tsari flour can also be used in the preparation of weaning foods, biscuits, couscous, dakuwa (snack food from millet-groundnut blend), and fura.

Sorghum Trials
P. Marley, D.A. Aba, J.A.Y. Shebayan, L. Bamaiyi, D. Rosenow

Sorghum production in Nigeria is affected by several constraints which include lack of improved varieties especially those that are medium to late maturing (most suitable for cultivation) in the Sudano-Guinean ecological zones. Other constraints include biotic constraints amongst others. Biotic constraints are mainly pest and diseases of which sorghum midge, stem borers and headbugs remain the major pest problems while anthracnose, grainmould, and smuts are the major disease problems. Although the IAR/INTSORMIL Collaborative Research Programme started late in 2001, seven trials were conducted in the 2001 cropping season. These were in the areas of Pathology and Breeding.

In the International Sorghum Anthracnose Virulence Nursery trial, nine lines including B.TX 398, IS 854, SC 283, IS 12467 R.TX 434, SC 326-6 (IS 3758), IS 18760, SC 414-12E (IS 2508) and IS 6959 were resistant (average disease score of 1-3). Two of these lines SC 326-6 (IS 3758) and SC 414-12E (IS 2508) have currently been selected alongside our materials (SK5912, KSV 8, NRL 3 and Yar'ruruka) for genetic mapping. Of 28 lines that could be evaluated, 9 lines were resistant to foliar anthracnose. All 28 lines were resistant to covered, loose, long, head smut and grain mould. Other foliar diseases especially grey leaf spot and leaf blight were not observed. Insect infestation could not be assessed due to low insect pressure. Nineteen of the lines were resistant to foliar anthracnose while three lines were susceptible.

Results of the *Striga* control nursery showed that lines 97-SB-F5-DT-63, 97- SB-F5-DT-64, MALISOR 92-1, SRN 39 and SAMSORG 41 (ICSV 111) supported low *Striga* infestation and also showed low number of stands infested with *Striga*. This indicates the lines are resistant to *S. hermonthica*. Lines CMDT 45 and SAMSORG 14 (KSV 8) had high *Striga* infestation, but SAMSORG 14 gave the highest grain yield. This clearly either indicates resistance or a high level of tolerance.

In the Advanced Medium Maturing trial, days to flowering ranged from 72.5 for entry 8(97-SB-F5DT-38) to 85 for entry 26 (SURENO 99L-1048). This shows low variation for that character (CV 5.55%). Plant height ranged from 95cm for entry 3 (97-SB-F5DT-149) to 272.5cm for entry 13 (97-SB-F5DT-97). There seems to be a wider variation in this trait (CV 42.41%) than in the previous one. Grain weight ranged from 266.7kg/ha for most of the entries to 1866.7 kg ha^{-1} for entries 21 and 25 (Samsorg 14 and ICSV 905). These are local varieties. Only entries 22, 23 and 24 (KL-2, makaho Da Wayo and Farar Dawa) gave yields above 1000 kg ha^{-1}. All the exotic materials performed below 700 kg ha^{-1}. There are still some promising materials if tested for another year to confirm their performance.

In the Advanced Late Maturing trial, days to 50% flowering ranged from 51 for entry 1(97-FA-FST-71-2) to 85 for entry 16 (Samsorg 17). There is low variation within these traits (CV 29.62%). Plant height ranged from 122.5cm for entry 5(97-SB-FST-154). The entries seemed to differ much in height (CV. 36-46%). For grain yield, it ranged from 333.3kg/ha for entries 5 and 7 (97-SB-F5DT-154 and 98-FA-FST-41) to 1133 kg ha^{-1} for entry 16 (Samsorg 17). Entry 16 is later than all other entries and gave the best yield. Entries 1, 8, 9, 10, 11 and 12 hold some promise in terms of yields.

It is expected that most of these trials will be established in the 2002 cropping season. Further, this collaborative program has started research and extension activities in the area of sorghum utilization. This involves the development of sorghum based food products and an improved charcoal – based oven for use in baking sorghum based products. This improved oven was developed in 2001 under the program and is currently under testing. This will be extended to rural women for enhancement of their income.

Burkina Faso

Mechanized Zaï Research

J.B. Taonda and Steve Mason

The traditional zaï system composed of planting pearl millet seed in a small hole with a small amount of manure increases water infiltration on some soils and results in increased yield, but requires considerable land labor. Scientists at INERA have developed a mechanized zaï using animal traction. The objective of this study was to determine the effectiveness of the mechanized zaï to the traditional zaï and a flat-planted control across six different soil types in Burkina Faso. The study was conducted on 12 farms in three villages with each farm considered a replication. The soil types present on the farms was sandy, sandy loam, sandy clay, clay, gravelly clay and gravel.

Pearl millet grain yields were over 1.0 Mg ha^{-1} on the sandy and clay soil, approximately 0.7 Mg ha^{-1} on the sandy clay, gravelly clay and gravelly soil, and 0.4 Mg ha^{-1} on the sandy loam soil, but no interaction between soil type and planting method was found. The traditional and mechanical zaï produced similar grain and stover yields, which were more than 0.4 Mg ha^{-1} more grain than the control and more than 1.4 Mg ha^{-1} more stover. The mechanized zaï has potential to produce the yield advantage associated with the traditional zaï system through use of animal traction, but with greatly reduced labor and economic cost. The manual zaï system requires approximately 300-man hours of labor/ha while the mechanized zaï requires approximately 22 man hours/ha.

Networking

INTSORMIL supported joint activities with the regional millet and sorghum networks, ROCEFREMI and ROCARS, respectively. Contacts have been made with **AFRICARE** and **World Vision International** in Niger. Africare heads a consortium of four NGO's receiving funding from USAID for a food security development project in Niger. World Vision supports seed activities in the Maradi region of Niger.

Partners in the Niger sorghum hybrid seed production effort include the IFAD/INRAN technology transfer project, the IFAD/Tillabery project, and the WINROCK-ONFARM project.

Southern Africa
(Botswana, Namibia, South Africa, Zambia, Zimbabwe)

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Collaborative Program

Organization, Management, Implementation and Financial Inputs

The INTSORMIL Southern Africa regional program involves six projects:

Pearl Millet Breeding: Development of pearl millet cultivars for dryland production, commercialization and industrial development in Southern Africa

Pathology: Disease management research, identification and use of resistance

Food quality: Food Quality

Pests: Genetic resistance to sugarcane aphid and integrated pest management in Botswana and South Africa

Production and Marketing: Identification of factors necessary to promote commercial sorghum production and processing in Botswana

Sorghum Breeding: Development of improved sorghum varieties and hybrids for Southern Africa

Through a Memoradum of Agreement with SADC/ICRISAT/SMIP the regional program is fully integrated with regionally planned sorghum and pearl millet research. This allows INTSORMIL funds to be disbursed to 15 collaborating NARS scientists in 5 countries. The scientists represent 9 research agencies. The SMINET regional coordinator at the ICRISAT SMIP Center at Matopos, Zimbabwe is also involved. Due to INTSORMIL's previous management of a major post graduate training program for the Southern Africa region (25 Ph.Ds and 50 MS's from 9 countries completed their degrees), many of the collaborating scientists in Southern Africa are INTSORMIL trained and had INTSORMIL PI's as their major advisors. Activities in each project are planned annually in conjunction with NARS collaborators and the Work Plans are reviewed at the SMIP Technololgy Transfer Program (SMINET) Steering Committee Meeting to ensure they continue to fit in the profile of work needed for development of sorghum and pearl millet production in the region.

Collaboration with Other Organizations

Research on pearl millet and sorghum breeding is organized with NARS scientists in collaboration with SMINET at Matopos, Zimbabwe to ensure complementarity with existing regional sorghum and pearl millet programs. Pearl millet breeding is conducted with the Ministry of Agriculture, Water and Rural Development, Tsumeb, Namibia; the Ministry of Agriculture, Botswana; and the Ministry of Agriculture, Kaoma Research Station, Kaoma, Zambia. Sorghum breeding is conducted with the Botswana College of Agriculture and the Ministry of Agriculture, Golden Valley Research Trust, Zambia. Grain quality research is with the University of Pretoria, CSIR (South Africa (SA)), and the Agriculture Research Corporation (ARC), SA. The CSIR has strong interactions with the private sector in the region which will assist in transfer of information to help private entrepreneurs. Entomology research is with the ARC Summer Grains Crop Institute, Potchefstroom, SA and the Dep. of Agricultural Research, Gaborone, Botswana. Plant pathology and ergot research is with the ARC Summer Grain Crops Institute, Potchefstroom, SA; Crops and Soil Research, Mt. Makulu Research Station, Chilanga, Zambia; Department of Agricultural Research, Gaborone, Botswana; the Plant Protection Research Institute, Harare, Zimbabwe; and the Medical Research Council, Tygerberg, SA. Marketing research is with the Botswana College of Agriculture.

The Planning Process

Research projects in breeding, pathology, entomology, and food quality are based on on-going linkages. Production and marketing research was based on availability of regional expertise. The future program will be shaped by priorities decided by SADC/NARS (SADC = Southern Africa Development Community) and the availability of matching INTSORMIL scientists and funds. INTSORMIL activity will continue to be developed as part of SMINET to ensure full integration with other regional sorghum and pearl millet research and development projects. Phase IV (initiated October, 1999) of the SMIP program to ICRISAT/Matopos focuses entirely on technology transfer. Since ICRISAT has no core funded scientists in the SADC region, INTSORMIL's participation in regional crops research is regarded as essential by SMINET and collaborating countries.

Sorghum and Pearl Millet Constraints Researched

Production and Utilization Constraints

Sorghum and pearl millet are major food crops in the SADC region, and sorghum is used to make opaque beer. Sorghum is the major cereal in Botswana and parts of Zambia, Mozambique, Malawi, and Tanzania, while pearl millet is the major cereal in Namibia and parts of Tanzania, Mozambique, Zambia, and Zimbabwe. Many constraints associated with low resource agriculture are present including low grain yield potential, infertile soils, variable moisture availability, numerous insect pests and diseases, and poor market structures. Genetic improvement and better disease or insect management can economically address some constraints by increasing grain yield potential and stress resistance, and by improving grain quality to meet end-use requirements. However, market channels need to be improved since sorghum varieties with the required quality to meet commercial consumer requirements frequently have inconsistent production. Availability of a consistent supply of improved quality sorghum and pearl millet for processing into value added urban products is a major problem limiting utilization. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. A strong need exists for developing a system of identity preservation for production, marketing, and processing.

New varieties and hybrids with increased grain yield potential, drought tolerance, and other desirable traits are in development by national programs. Exotic sorghums and pearl millets are continually introduced into the SADC region. It is imperative that improved cultivars have resistance to major endemic disease pathogens and pests, excellent environmental adaptation, and improved end-use traits. Identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will assist the NARS teams in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and in similar SADC environments.

Constraints Addressed by Project Objectives

Pearl Millet Breeding: Develop top cross grain and forage hybrids adapted to low rainfall regimes in Southern Africa suitable for commercialization and stimulating industrial development, test prototype cultivars in commercial and industrial ventures, develop appropriate populations for sustaining the program.

Pathology: Identify adapted, agronomically desirable sources of resistance to major foliar pathogens and charcoal rot, including drought tolerance and resistance to sugarcane aphid where feasible. Identify viruses occurring on sorghum in Botswana and Zambia, determine vulnerability in recently released sorghums and the need for better sources of resistance. Integrate resistant cultivars from various nurseries into a SADC regional nursery. Determine mycotoxin production capabilities of new *Fusarium* species, and the presence of *Fusarium* mycotoxins in grain-molded grain.

Food Quality: Determine the physical, chemical and processing properties of local and improved sorghum and millets. Improve the quality of food products by modification of processes to reduce or eliminate anti-nutritional components. Summarize existing information on quality and utilization and transfer the information on utilization quality to potential users.

Insects: Reduce yield losses by identifying, evaluating, and incorporating sugarcane aphid resistance into sorghum varieties and hybrids adapted to Southern African agricultural systems. Develop integrated pest management strategies for sorghum insect pests in Southern Africa.

Production and Marketing: Through structural village surveys and country-wide equilibrium analysis, identify alternative feasible sources of supply for sustainable sorghum processing in Botswana and their distributional economic welfare impacts.

Sorghum Breeding: Develop high grain yield sorghum varieties and hybrids with improved quality traits for food, forage and feed and adaptation to drought prone areas in Botswana, Zambia and Zimbabwe. Enhance disease and pest resistance with improved germplasm or elite lines. Assist with seed production and distribution systems at a community level

Research Progress

Pearl Millet Breeding

Zambia

Research centered on three major areas 1)Male-parent heterosis, 2)Female (Donor-parent) Effect, and Germplasm exchange. For male-parent heterosis, - the on-going backcrossing program (currently testing the second backcross and developing the third backcross) continued. The were 45 BC_2's evaluated and generally there was: 1)declining male-parent heterosis for grain yield (only 8 BCs show heterosis); 2)uniformity in flowering (61-66 days) for backcrosses regardless on donor or recurrent parent influence; 3)variability for traits such as tillering (1.90-3.90 tillers/plant), head length (28-45cm), and threshing percentage (56-85%).

For female (donor-parent) effect, trait expression varied with the parent. Generally, backcrosses derived from 863 B-P_3, IP 18293 and Tift 23DB-P_1 were better for grain yield. Backcrosses derived from on Tift DB-P_1, 841B-P3 and IP 18293 expressed excellent tillering. Good head-length was obtained in backcrosses derived from 841B-P3, PT732 B-P_1 and ICMP 85410-P_7. Specific backcrosses excellent for certain traits were identified: Tift DB-P_1 x NEC for grain yield; 841B-P3 x NEC for tillering; IP 18293 × ZPMBC for early flowering; 97C 77229 x ZPMV 92008 and ICMP 85410-p7 x NLC for head length; and 863B-P_3 x NLoC for threshing percentage.

Collaboration was established with ARS-204 to test genotypes in Zambia. A 30-entry trial that included genotypes from ARS-204, University of Nebraska, West Africa, SADC-SMIP, and Zambia was assembled and planted at Longe (medium rainfall), and Lusitu (low and erratic rainfall). The test at Lusitu failed due to drought. At Longe, the experimental hybrids, WA-26 and WA-23, were significantly superior to all checks except Kuomboka. Seed stocks of lines obtained from ARS-204 and the University of Nebraska were increased.

Botswana

The current drought showed the superiority of pearl millet over other crops. Twenty-five new hybrids were evaluated in a 5x5 lattice design. Nine hybrids with good agronomic traits and grain yield were identified for continued testing. Most of the hybrids were in the early (based on days to 50% anthesis) maturity class. The hybrids are also medium height 1.7m and less susceptible to lodging. Taller, later maturing hybrids were discarded.

Sorghum breeding

Zambia

The overall goal of the breeding program is to develop alternative cereal crops for drought prone areas deficit in food. Increased sorghum production and use is expected to provide household food security and increased income for the subsistence farming sector. Specific objectives are: 1)Develop high yielding varieties and hybrids suitable for food, feed, brewing for the different agro-ecological regions with good general resistance to all economically important diseases and pests; 2)Develop appropriate agronomic management practices for each agro-ecological region and farming system, and to work as a catalyst in the transfer of technology. In order to meet this objective the team is closely working with developmental teams within the research branch and various provincial units and other extension agencies including NGO's; 3)Maintain pre-basic and basic seeds of all released and pre-released varieties, hybrids and their parents; 4)Identify various biotic and abiotic production constraints of sorghum and millet and develop control measures.

In 2001-2002 season the following INTSORMIL trials that were received late the previous growing season were planted: ARGN (Anthracnose Resistant Germplasm Nursery), ISVN (International Sorghum Virus Nursery), SABN (Southern Africa Breeding Nursery), SAT (Sugarcane Aphid Test), DLT (Drought Line Test), and DHT (Drought Hybrid Test).

One of the main program objectives is to generate genetic diversity through collections, introductions and hybridization. Program emphasis has now shifted to target not only small-scale farmers but also commercial end-users. The development of sorghum varieties suitable for food, brewing, feed and forage is now a major emphasis. It is important to evaluate promising lines for grain yield and other agronomic traits, and to maintain and increase seed of released varieties. A total of eight trials were evaluated at Golden Valley Agricultural Research Trust and Lusitu.

The 2001/2002 season was hindered by erratic rainfall significantly below normal. Trials at most of the testing sites failed. However trials for forage, brewing, feed and food were evaluated at Golden Valley Agricultural Research Trust. Excellent conditions existed to select for diseases and other pests. In the Sorghum Advanced Variety trial the mean grain yield was 3180 kg ha^{-1}. A new variety [Framida x SDS 3845] F6-5 (brewing type) had a mean grain yield of 4325kg ha^{-1}. Other new promising varieties with high mean yields were SDS 4882-1, ZSV-13 and [WSV 387 x ICSV 108] F4-4. The checks ZSV-15, Kuyuma and Sima all had low mean yield. Visual selections were made in test crosses, introductions, F2 populations, segregating generations. Selected materials will be evaluated further next season.

Seed of released varieties was maintained and increased. The germplasm evaluated included 49 pairs of A & B lines; 134 lines for seed increase; 155 experimental crosses and 70 test crosses. Seed of ZSV-15, SDS 4340 A & B, SDS 4283 A & B, A 155 & B, Sima and Kuyuma were increased in isolation fields.

Availability of improved seed to producers and end-users continues to be a major hindrance and challenge to the program. Seed of the released varieties cannot be produced by seed companies citing low demand. The research program and NGO's such as PAM-SHAPES (Program Against Malnutrition - Small Holder Access to Processing, Extension and Seeds Project), have embarked on seed multiplication activities at the village level. The approach is to identify one or two prominent village farmers that will produce seed for sale in the village itself. Extension officers monitor the seed growers. Seed of released varieties such as Kuyuma, Sima and parental lines were produced in isolation. Because of the drought experienced in most parts of the country, very little seed will be available for farmers in the next growing season. This situation could continue for the next two seasons and calls for some intervention to alleviate the shortage of improved seed.

Education on the benefits of new technology (varieties) continued through field days at Golden Valley Agricultural Research Trust and Mt. Makulu Research Station. Small scale farmers and industry representatives participated and were offered the opportunity to see several promising improved varieties and products. Significant interest was generated with the kind of products that can be made from improved sorghum and millet.

Botswana

There were two major research thrusts in 2001/2002 - 1)Evaluation of a sorghum advanced hybrid and variety trial for grain yield and milling quality; and 2)development of new hybrid parental lines. In the hybrid and variety trial, 25 sorghum hybrids and 36 varieties were evaluated at the Notwane farm. The main objective was to identify new genotypes with good adaptation to local conditions and good grain. Based on performance (compared to Phofu and Segaolane) 9 new hybrids and 10 varieties were identified. The best hybrids produced 2 to 3 tons per hectare while the best variety produced 1.5 tons per hectare with little rainfall (less than 350 mm). Most genotypes were medium-maturity (70-80 days to 50% flowering) and semi-dwarf (1.45m to 1.90 m in height) with tan plants and white hard grain which is preferred by millers and consumers. Entries selected for further milling quality tests include SDSH98009, SDSH 94004, SDSH 328, ICSH 93107. For parental line development the fifth backcross for new A-lines was completed. Twenty backcross plants were selected. Selections were based on uniformity, good maturity nick between recurrent and non-recurrent paired rows, good seed set, early maturity, drought tolerance and excellent grain quality. A-lines were testcrossed to Larsyvat 46-85, a well adapted restorer line ready for release. The test crosses will be evaluated in the 2002-03 season for yield potential and fertility.

Regional Activities

Additional breeding activity is directed at the release of high grain yield cultivars that can be used for food and/or brewing. To disseminate improved varieties, seed is increased to supply to farmers, extension, non-governmental organization (NGOs), seed producers, etc., for small-scale seed multiplication and on-farm demonstrations. Nurseries such as the ADIN, Drought Lint Test, Southern Africa Observation, International Sorghum Virus, and Sugarcane Aphid resistance are distributed regionally. Drought during the 2001/2002 growing season severely hindered research and caused several locations to be abandoned.

Plant Pathology

South Africa

Nurseries were planted at Bethlehem, Cedara and Potchefstroom and included local commercial hybrids, the All Disease and Insect Nursery (ADIN), Southern African Breeding Nursery (SABN) and 68 experimental hybrids. Principal diseases targeted for study include damping-off and seedling blight, root rot, leaf blight, ergot and grain mold.

Leaf blight was particularly severe at Cedara and only four commercial hybrids had mean ratings less than 1 on a 0-5 rating scale. These included NK283, which currently makes up approximately 50% of local production. Within the ADIN and SABN nurseries, 6 and 2 entries respectively, remained free from leaf blight while 21 and 18 respectively, had ratings less than 1. Mean leaf blight severities were 1.5 and 1.7 in the ADIN and SABN, respectively. Ergot susceptibility within these nurseries varied and 19 entries in the ADIN had mean ergot severities of less than 10% while 20 entries had ergot severities exceeding 30%. In the SABN 18 entries remained ergot free indicating good pollen viability and self-pollination efficiency in a significant number of entries. Local commercial germplasm was resistant to ergot indicating that selection for cold tolerance and pollination efficacy over a number of seasons has contributed significantly to ergot resistance. Grain mold severity was high and only 5 entries in the ADIN had mean grain mold ratings less than 1 while 52 entries had ratings exceeding 2. In the SABN no ratings less than 1 were recorded and only 11 entries had ratings less than 2, indicating relatively high susceptibility to the disease complex. Within local experimental hybrids, the line SA2063 derived from (IS12612c) appeared to be a good source of heritable leaf blight resistance. Fourteen selections from the ADIN and 22 from the SABN were incorporated into local nurseries and their adaptability to small farmer conditions will be determined during 2002/03.

Increased awareness of grain molds has led to this disease complex receiving greater local attention. Primary isolates from grains were *Fusarium* spp. (mainly *Fusarium graminearum* and *F. subglutinans*), *Alternaria alternata*, *Curvularia clavata* and *Phoma sorghina*. Initial evaluation for aflotoxins and fumonisins in grain from five hybrids, planted at three localities over three planting dates, indicated that these toxins were not present at detectable levels. Additional analyses, including moniliformin, DON and zearalenone are still being conducted. *C. clavata* and *F. proliferatum* were primary isolates from excised embryos. There was a significant correlation between the isolation of pathogens from embryos, reduced seed germination and seedling vigor. Grains were particularly susceptible to infection during milk and soft dough stages of grain development. Under greenhouse conditions, germination was reduced by an excess of 50% when heads were inoculated with primary grain mold pathogens at the susceptible stage. Risk analysis based on weather x grain mold interactions in field trials, suggested that the most critical period for infection is 9-13 days after anthesis. Humidity proved a critical factor and RH >86% is essential for infection. Grain mold severity, rated on a visual 0-5 scale, was highly negatively correlated (R^2=0.94) with hardness and subsequent milling quality. Similarly, reduced germination significantly reduced malt quality (diastatic power).

Under local conditions, ergot severities in unsprayed seed production plots are estimated to average 10-20% with some plots showing 40% or more. Protection of the ovary during the critical period reduces losses due to the disease and increases grain quality. Ergot research to develop a multivariate, risk analysis model continued although dry, hot conditions at Potchefstroom and Bethlehem did not favor ergot development. Attempts to finalize this component and verify model accuracy was suspended until 2002/2003. Fungicides were evaluated for ergot control at Cedara were propiconizole, tebuconazole, tridimenol, tridimefon, and a strobilurin. Significant interactions were recorded between fungicide and application time. Applications prior to anthesis tended to be least effective while applications after anthesis gave best control. This suggested that translocation to the infection site is via the floret and that floret gaping promotes chemical uptake. Triadimenol and triadimefon were the most effective fungicides while propaconizole and tebuconizole were less effective.

Mean root rot severity in commercial sorghum hybrids evaluated at Bethlehem and Potchefstroom ranged from 30.30% to 41.26%, indicating that most local commercial germplasm is susceptible to the disease complex. Variance components based on sums of squares indicate that the effects of genotype, environment and GxE interaction are respectively 15.13 %, 70.51 % and 9.09 % for root discolouration and 4.08 %, 80.85 % and 10.59 % for root volume. Environment was clearly the primary influence on both root rot and root volume of sorghum with genetic components having a relatively small effect on recorded variation. This would indicate that control of the disease, at least in the short to medium term, will have to be achieved through manipulation of the environment using production practices. Additive main effects and multiplicative interaction analyses (AMMI) was successful in identifying those hybrids in which root rot and root volume were more stable over changing environments.

At the Medical Research Council, seven sorghum and seven pearl millet samples were obtained from village granaries in Mali. Grain from these samples was analyzed for fumonisins by using high-pressure liquid chromatography (HPLC) and liquid chromatography-mass spectrometry (LC/MS). The seven pearl millet samples contained between 5 and 70 ppb (mean, 24 ppb) total fumonisins, with only one sample containing fumonisins (FB_2 and FB_3) other than FB_1. Six of the seven sorghum samples contained between 10 and 40 ppb (mean, 20 ppb), with only one of these samples containing a fumonisin (FB_2) other than fumonisin B_1. The seventh sorghum sample contained over 1000 ppb of total fumonisins, and higher levels of all three fumonisins (FB_1 – 360, FB_2 – 345 and FB_3 – 320 ppb). In a diet based primarily on sorghum, the amount of total fumonisins consumed in food from this sample probably would exceed the Joint FAO/WHO Expert Committee on Food Additives provisional Maximum Tolerable Daily Intake level for this toxin of 2 µg/kg of body weight for humans, e.g., a 70-kg person would need to eat 140 g of sorghum from this sample to exceed this level of fumonisins in the diet. This report is the first of the natural occurrence of fumonisins in pearl millet and the first LC/MS confirmed report of fumonisins in pearl millet. Four identifiable *Fusarium* species and at least three other *Fusarium* spp., the putative source of these toxins, were recovered from these sorghum and pearl millet grain samples. Techniques beyond observation in the light microscope are required to accurately identify the bulk of the fungal cultures as a significant proportion appear to belong to previously undescribed species. Further characterization and identification of these strains with molecular techniques will be made by Dr. Leslie at Kansas State University.

Botswana

Trials planted to evaluate for disease severity were the International Sorghum Virus Nursery (ISVN), the Southern Africa breeding nursery (SABN), and the ADIN (data not reported due to lack of disease symptoms). The ISVN was evaluated at Sebele and Pandamatenga for reaction to sugarcane mosaic virus (SCMV). Disease incidence was recorded as the total number of plant displaying virus symptoms in each plant, and disease severity was recorded using standard visual ratings for scoring the approximate percentage of leaf area affected by the virus. Susceptible entries were Mahube, New Mexico 31, BTx378, and Tx7000. Tolerant cultivars were Atlas, Bugoff, SC175-14E, SA384 (Combine Shallu), P135038, Tx3048, Hegari, and Tx398. Resistant cultivars were Tx2786, BTx430, Tx09, QL11, QL3 (India), Tx623, and Tx2858.

The SABN was evaluated for reaction to grain mold, sorghum downy mildew, rust, leaf blight, sooty stripe, red leaf strip, and sugarcane mosaic virus at Pandamatenga. Lines with no symptoms for any disease scored include: (B1*Town)-HL?-HL1, (BTx635*B4)-HF4, CE151, Sureno, 86EO361, Kuyuma, Sima, Tegemeo, WM#177, ZSV15, 90EO328, (CE151*BDM499)-LD17-BE1, (SRN39*90EO328)-HF4-CA1, (Sureo *SRN39)-BE15-CWBK-BE1, (Sureno*SRN39)-BE!-CW5-BE2, several derivatives of (86EO366*WSV387), (86EO361*Macia)-HF25, (M84-7*WSV387)-HD7, (Macia*Dorado)-LL7, and (CE151*MP531)-DL47.

Food Quality

Dr. Leda Hugo (Mozambique) completed her Ph.D. program at the University of Pretoria. Her research demonstrated that malting and fermentation improved the baking properties of sorghum flour in composite breads like those made in Southern Africa. The fermentation procedure was the most promising and practical method and made good bread containing 30% sorghum. The soured or fermented sorghum paste could be added directly to the wheat flour and with slight modifications to the current procedure could be utilized to effectively incorporate sorghum flour into bread baking. It also improved the in vitro digestibility of the protein of the sorghum. Dissertation citation: Hugo, L.F. 2002 Malted and Fermented Sorghum as Ingredient in Composite Breads. Ph.D Dissertation. U of Pretoria, Pretoria, S. Africa 171pp

Cooperative research underway with the Dep. of Food Science, Univ. of Pretoria is providing insights into improved sorghum and pearl millet processing and utilization. Through this collaboration INTSORMIL is able to reach the next generation of African food industry leaders. The following research projects are underway to support improved end-use of sorghum and pearl millet:

Optimization of pearl millet milling - In Namibia, pearl millet milling is a rapidly growing entrepreneurial business and improving food security by encouraging increased cultivation of the grain. The milling process being used is highly complex and inefficient. It involves: dehulling of the grain, steeping/fermentation, partial solar drying, wet milling with a hammer mill, and solar drying of the flour. A Namibian masters student under the supervision of Drs. Taylor (Univ. of Pretoria) and Rooney (TAMU), will study the role of pearl millet grain quality and the effect of various processing parameters on the efficiency of the milling process and the nutritional quality of the resulting flour.

Optimization of sorghum roller milling - Small double-roller mills can be used to mill sorghum and revolutionize the production of quality sorghum meal meal throughout Africa. However, the optimum processing parameters, such as conditioning levels and times, for the various types of sorghum, (e.g., white tan, red pericarp, tannin) are not known. This places sorghum at a competitive disadvantage with respect to other grains, particularly maize, since low extraction levels and poor quality flour/meal are obtained. A South African masters student, under the supervision of Drs. Taylor and Rooney and in collaboration with a leading South African small company roller mill manufacturer, will study the role of sorghum grain quality and the effects of various processing parameters, including conditioning and roller settings, on the efficiency of the roller milling process in terms of extraction rate and flour/meal quality.

Research is on-going to develop sorghum grain end-use standards for breeding with respect to injera making quality. The research is a doctoral research project conducted by Mrs. S. Yetneberk of the Nazret Institute of Agricultural Research, Ethiopia, under the joint supervision of Drs. Taylor and Rooney.

Research is on-going to study the natural shelf-life extension of food. This research is sponsored primarily by the National Research Foundation of South Africa and the European Union. There are three major objectives to the research: 1)Study the antioxidant potential of sorghum milling by-products for food shelf-life extension; 2)Develop of sorghum protein biofilms to extend the shelf-life of Southern African fruit and nut exports; 3)Through competitive microbes suppress fungal contamination and pathogens in sorghum malting.

Insect Pest Management

Four experiments (two sugarcane aphid screening trials, one greenhouse screening trial for sugarcane aphid and a midge line test) were conducted during the 2001/2002 cropping season.

Sugarcane Aphid Screening Trials

Two field trials (100 entries x 3 replications) were planted, one at the mid-altitude research station of the ARC-Grain Crops Institute at Potchefstroom and one at the sub-tropical low-altitude station at Burgershall. Sorghum was planted late in the growing season (late December) to increase the likelihood of high levels of aphid infestation. Aphid damage was evaluated when the majority of the hybrids were flowering. The severity of infestation was evaluated using a 1 to 5 scale where, 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present on two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered to be resistant to damage while a rating of 3 indicated intermediate levels of resistance. Plants with a rating of 4 and 5 were considered to be susceptible.

Sugarcane aphid infestation levels at the Burgershall field station were significantly lower than at Potchefstroom. Only 3 % of the entries rated a 3 (medium infestation levels). No conclusive results could therefore be made from this field trial. The grain yield expression experimental entries was superior to that at Potchefstroom. Leaf diseases were also common. In the future this station will be used for disease evaluation as well. Infestation levels at the Potchefstroom site were high. Results indicated that 29 % of the entries rated below a 2 (indicating none to light damage). Three entries (6BRON161, TAM 428, and (Macia* TAM428)) had no aphids on any of the plants in any replication.

In a greenhouse trial resistance to sugarcane aphid was evaluated during the seedling stage with artificial infestation. Results indicated that 30 % of the entries exhibited no damage symptoms 22 days after inoculation while the whole plot row of 37 % of the entries were dead. Results from this trial will be used to develop the 2003 Sugarcane Aphid Trial.

Midge Line Test

One field trial (85 entries x 3 replications) was planted at the ARC-Grain Crops Institute, Potchefstroom. No midge infestation occurred at this locality. However, sugarcane aphid infestation levels were high and aphid damage was evaluated on the 1 to 5 scale when the majority of the entries were flowering. Six entries had no aphid infestation and were considered highly resistant. These entries (TAM2566, MLT180, MLT181, Tx2882*SRN39, BVar*MB102-3 (source 00LI1338), BVar*MB102-3 (source 00LI1339)) will be included in the 2003 Sugarcane aphid test.

Mutuality of Benefits

Productivity and utilization of both sorghum and pearl millet will ultimately be improved both in SADC countries and the USA through joint research. Reciprocal germplasm flow is mutually beneficial. Basic research from the USA can often be adapted for use in developing countries where grain yield potential, adaptation, stress resistance, and grain quality need to be increased. U. S. pathologists and entomologists can become familiar with diseases and insects not yet present in the USA, or find new resistance sources to existing pests. For example, research in South Africa on sources of ergot resistance, understanding environmental conditions conducive to disease spread, and methods of research are of vital interest to U.S. scientists. Nutritional components of food quality researched in collaborative projects have relevance to grain values for livestock feed.

Institution Building

Equipment and Supplies

One computer and printer was delivered to the Zambia pearl millet breeding program.

One computer and printer was delivered to the Zimbabwe sorghum breeding program

Training of Host Country Researchers

Through a previous regional USAID program INTSORMIL provided long-term training to a large number of SADC sorghum and pearl millet scientists. Currently one regional scientist is selected each year for a short-term training assignment with a U.S. principal investigator. Mr. F. Muuka, pearl millet breeder, participated in a short-term training assignment in August 2001 with Dr. Wayne Hanna (USDA-ARS/INTSORMIL). Mr. Leo Mpofu, sorghum breeder, was selected for a short-term training assignment in July-August 2002 with Dr. Bill Rooney (TAM-220) and Dr. Gary Peterson (TAM-223).

Plans were initiated for Rachel Ngulube-Msikita (Zambia) to travel to the University of Nebraska to complete her M.S. Degree with Dr. Jerry Eastin.

Ms Leda Hugo completed her Ph.D in food science and technology at the U of Pretoria. She has returned to Mozambique where she is a professor at U of Eduarado Mondolane. Professor Taylor, University of Pretoria was her major professor.

Under the supervision of Dr. J.R.N. Taylor the University of Pretoria Food Quality Laboratory has participated in graduate training as advisor or co-advisor of 4 Ph.D. students (Ghana -1, Zimbabwe-2, South Africa-1) and 10 M.S. students (Botswana-1, Ghana -1, Kenya-1, Mozambique-1, Nigeria-1, South Africa-2, Uganda-1, Zimbabwe 2). Dr. Taylor advises 4 M.S. and 6 Ph.D. students from 8 African countries in sorghum and millet food science and technology.

Additional short- or long-term training will occur as individuals and funds are identified, and a regional strategy will be developed at the INTSORMIL Principal Investigators in November, 2002.

Mr. Hoffman (Namibia) conferred with INTSORMIL scientists regarding pearl millet research and training opportunities.

Host Country and U.S. Scientist Visits

John Leslie discussed INTSORMIL research with collaborators in South Africa in November, 2002.

Gary Peterson, Bonnie Pendleton, and Darrell Rosenow visited Botswana, Zambia and South Africa 1-13 April 2002. In Botswana met with Department of Agricultural Research scientists to plan future research activity. Met with Botswana College of Agriculture administrators and scientists to discuss initiating additional collaborative research in plant breeding and entomology, and potential in other disciplines. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss sorghum and pearl millet research. Evaluated sorghum research plots at Golden Valley and Siavonga region. Discussed INTSORMIL Southern Africa activity with USAID/Zambia representatives. In South Africa, met with collaborators at the ARC, Potchefstroom, to evaluate collaborative activity and plan future research. Evaluated sorghum research plots at the Cedera Research Station near Hilton, the ARC at Potchefstroom, and the Lowveld Station near Hazyview. Also met with Dr. John Taylor at the University of Pretoria to discuss sorghum and pearl millet grain quality research.

Medson Chisi participated in the INTSORMIL Regional Coordinators and Technical Committee meetings at the University of Nebraska 30 April - 3 May 2002.

Germplasm Exchange

Several hundred sorghum lines and cultivars were provided to evaluate for reaction to various diseases, adaptation, drought response, and sugarcane aphid resistance in the SADC region in the 2001-2002 growing season (collaborative with TAM - 222, TAM - 223, and Dr. B. Rooney (now TAMU - 220)). Millet germplasm to Zambia was provided by ARS-204.

Networking

An efficient sorghum and millet research and technology transfer network exists in the SADC region conducted by the SMIP program and INTSORMIL's SADC collaborative research program is completely integrated on a regional basis. The Zimbabwe unrest and political situation has imposed significant restrictions and a reduction of activity in Zimbabwe. Interaction with the Univ. of Pretoria, Council for Science & Industrial Research, South Africa in sorghum and pearl millet utilization research efficiently utilizes scarce resources and personnel. Graduate students in the Food Science Department at the University of Pretoria are from many other African countries. Many of them are participating in the Regional Master of Science program which consists of joint programs between CSIR and University of Pretoria. The regional program has the goal of providing education for African scientists on African crops that are of importance in the region. Sorghum and millets are a key components of these food systems. Thus, interactions with this program informs many future African food industry leaders on the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL can provide assistance to the region by involvement in these programs where possible. Through allocation of resources INTSORMIL has started encouraging regional scientists to collaborate across countries.

Program Accomplishments

INTSORMIL is fully integrated into the SADC and SMIP sorghum and pearl millet regional research and technology transfer activities. INTSORMIL regional work plans are annually reviewed by the SMINET Steering Committee.

Factors influencing the incidence and control of sorghum ergot are now better understood, leading to better control of the disease, especially in hybrid production fields.

New sorghum and pearl millet varieties and hybrids are ready for release or in final testing prior to release. A large number of sorghum germplasm has been characterized for resistance to major diseases and sugarcane aphid. Multi-location testing of sets of such lines provides strategic ecogeographic information on distribution and severity of diseases.

Collaboators at the Department.of Food Science, University of Pretoria presented the following short-courses to improve the food technology skills of professionals in the sorghum and millet food industry in Southern Africa. 1)Course in sorghum malting technology has been presented to six groups of 12 people over the past 8 years. 2)Short course in opaque (sorghum) beer brewing has been presented annually to a total of some 150 people from throughout southern Africa over the past 6 years. 3)Under the sponsorship of the FAO and the Namibian government a pearl millet processing technology training facility has been designed and is the process of being constructed in northern Namibia.

Research into improving sorghum processing technologies is being carried out for the sorghum food industry in South Africa through its industry body, the Sorghum Forum. With the support of the USAID RAPID Program, (Regional Activity to Promote Integration through Dialogue and Policy Implementation) sorghum grain end-use quality standards and methods have been developed to facilitate grain trade in southern Africa. Technical assistance has been rendered to the Botswana Bureau of Standards to implement sorghum grain standards incorporating these concepts and methods, and to Tanzanian businesses in the setting up of a sorghum industry forum.

The Department of Food Science, University of Pretoria and CSIR Bio/Chemtek in South Africa are the official SADC (Southern African Development Community) center for post-graduate training in Food Science and Technology. Because of the economic importance of sorghum and millets to the Region, a high percentage of post-graduate training involves research into these grains. Currently 4 masters and 6 doctoral students from 8 African countries are being trained sorghum and millet food science and technology. INTSORMIL collaboration with the Dep. of Food Science provides additional mutually beneficial training and research opportunities.

Factors influencing incidence and control or sorghum ergot have been identified leading to better understanding of the disease mechanisms. Fungicides for control of ergot have been evaluated and significant interactions between fungicide and application time identified.

Educational Activities

Year 23 INTSORMIL Degree Training Participants July 1, 2001 - June 30, 2002

Name	Country	Univ.	Discipline	Advisor	Degree	Gen-der	Funding
Kathol, Delon	U.S.	UNL	Agronomy	Mason	MSC	M	I
Maman, Nouri	Niger	UNL	Agron/Physiol	Mason	PHD	M	P
Seibou, Pale	Burkina Faso	UNL	Agronomy	Mason	MSC	M	I
Xerinda, Soares	Mozambique	UNL	Agronomy	Wortmann/Mamo	MSC	M	IC
Kriegshauser, Travis	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
Ellicott, Alexis	U.S.	PRF	Breeding	Ejeta	PHD	F	P
Gunaratna, Nilupa	U.S.	PRF	Breeding	Ejeta	MSC	F	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	I
Phillips, Felicia	U.S.	PRF	Breeding	Ejeta	MSC	F	P
Mateo, Rafael	Honduras	TAM	Breeding	W.L. Rooney	PHD	M	I
Coulibaly, Sidi Bekaye	Mali	TTU	Breeding	Rosenow/Peterson	PHD	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	P
Traore, Karim	Mali	TAM	Breeding	Rosenow/Peterson	PHD	M	P
Tahirou, Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	I
Uaiene, Rafael Nemba	Mozambique	PRF	Economics	Sanders	MSC	M	IC
Wubeneh, Nega G.	Ethiopia	PRF	Eonomics	Sanders	MSC	M	I
Ayyanath, Muralimohan	India	WTU	Entomology	Pendleton	MSC	M	P
Palousek, Anastasia L.	U.S.	WTU	Entomology	Pendleton	MSC	F	P
Sambaraju, Kishan Rao	India	WTU	Entomology	Pendleton	MSC	M	P
Veerabomma, Suresh	India	WTU	Entomology	Pendleton	MSC	M	P
Gorena, Roberto Luis	U.S.	TAM	Entomology	Peterson	PHD	M	P
Johnson, Zeledon	Nicaragua	MSU	Entomology	Pitre	PHD	M	I
Bugusu, Betty	Kenya	PRF	Food Sciences	Hamaker	PHD	F	I
Maladen, Michelle	India	PRF	Food Sciences	Hamaker	MSC	F	I
Suhendra, Budhi	Indonesia	PRF	Food Sciences	Hamaker	MSC	M	P
Acosta, David	Mexico	TAM	Food Sciencesl	L. Rooney/Waniska	MSC	M	P
Awika, Joseph Mobutu	Kenya	TAM	Food Sciences	L. Rooney/Waniska	MSC	M	P
Awika, Joseph Mobutu	Kenya	TAM	Food Sciences	L. Rooney/Waniska	PHD	M	P
Bueso, Francisco (Javier)	Honduras	TAM	Food Sciences	L. Rooney/Waniska	PHD	M	P
Gordon, Leigh Ann	U.S.	TAM	Food Sciences	L. Rooney	MSC	F	P
Mitre-Dieste, Marcelo	Mexico	TAM	Food Sciences	L. Rooney	MSC	M	P
Maranphal, Nitit (Finn)	Thailand	TAM	Food Sciences	L. Rooney/Waniska	MSC	M	P
Rudiger, Crystal	U.S.	TAM	Food Sciences	L. Rooney	MSC	F	P
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	PHD	M	P
Salah, Amgad	Egypt	KSU	Pathology	Leslie	PHD	M	P

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
IC = InterCRSP Funding

KSU = Kansas State University
MSU= Mississippi State University
PRF = Purdue University
TAM= Texas A&M University
TTU = Texas Tech University
UNL = University of Nebraska - Lincoln
USDA= Tifton, Georgia
WTU = West Texas A&M University

Year 23 INTSORMIL Non-Degree Educational Activities July 1, 2001 - June 30, 2002

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Duarte, Aildson	Brazil	UNL	Agronomy	Mason	VS	M	P
Grenier, Cecile	France	PRF	Breeding	Ejeta	VS	F	I
Hoffman, Jurgens	Namibia	USDA/ARS/GA	Breeding	Hanna	VS	M	P
Muuka, Ferdinand	Zambia	USDA/ARS/GA	Breeding	Hanna	VS	M	I
Atokple, Ibrahim	Ghana	TAM	Breeding	Rosenow/Toure	VS	M	I
Atokple, Ibrahim	Ghana	TAM	Breeding	Rosenow/Peterson	PD	M	I
Clara, Rene	El Salvador	TAM	Breeding	Rosenow/Peterson	VS	M	I
Deras, Hector	El Salvador	TAM	Breeding	Rosenow/Peterson	VS	M	I
Obando, Rafael	Nicaragua	TAM	Breeding	Rosenow/Peterson	VS	M	I
Toure, Aboubacar (3-trips)	Mali	TAM	Breeding	Rosenow	VS	M	I
Traore Kissima	Mali	TAM	Breeding	Rosenow/Peterson	VS	M	I
Aboubacar, Adam	Niger	PRF	Food Sciences	Hamaker	PD	M	P
Grenier, Cecile	France	PRF	*Striga*-Niger	Ejeta	VS	F	P
Grenier, Cecile	France	PRF	*Striga* Research	Ejeta	VS	F	P
Hess, Dale	U.S.	PRF	*Striga* Research	Ejeta	PD	M	I
Jurgenson, Jim	U.S.	KSU	Pathology	Leslie	VS	M	P
Zeller, Kurt	U.S.	KSU	Pathology	Leslie	PD	M	P
Little, Chris	U.S.	TAM	Poultry Nutrition	W.Rooncy	PD	M	P

VS = Visiting Scientist
PD = Post Doctoral

Year 23 Conference/Workshop Activities July 1, 2001 - June 30, 2002

Workshop/Conference	Location	Date	Participants Male	Female	Total
ASA Meetings	Charlotte, NC	Oct. 21-27, 2001	1	1	2
Parasitic Weed Symposium	France	May 30-June 22, 2001	1	1	2
Diarisso Yaro, Niamoye	Quito, Equador	April 3-4, 2002		1	1
Toure, Abdoul Wahab	Montrieuil, France	Nov. 14-23, 2001	1		1
Toure, Aboubacar	Chicago, IL	Dec. 5-7, 2001	1		1
Fungal Genetics Short Course	Sydney, Australia	May 2002	2	10	12
Fusarium Workshop	Sydney, Australia	June 23-28, 2002	22	20	42
Scientific Writing Workshop	Tygerberg, South Africa	Dec. 11, 2000	10	13	23
Scientific Writing Workshop	India (ICRISAT)	October 19, 2001	32	8	40
Scientific Writing Workshop	South Africa	November 3, 2001	40	20	60
Scientific Writing Workshop	South Africa	November 12, 2001	42	50	92
Scientific Writing Workshop	Mudgee, Australia	February 7, 2002	23	12	35
Scientific Writing Workshop	Brisbane, Australia	May 17, 2002	13	25	38
Sorghum Pests & Diseases	Managua, Nicaragua	June 10-14, 2002	27	13	40
Total					**389**

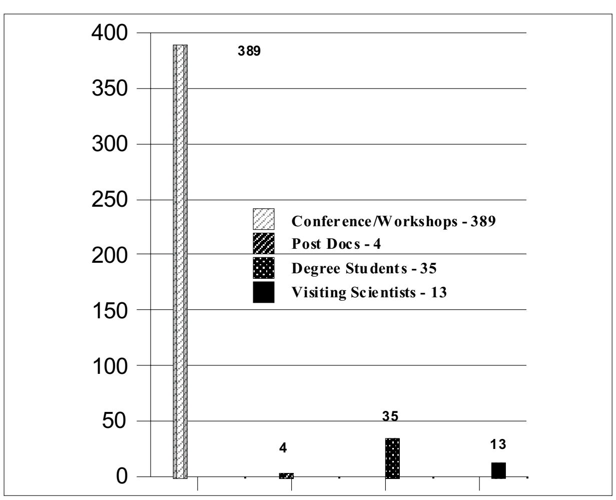

Figure 5. Total participants in educational activities.

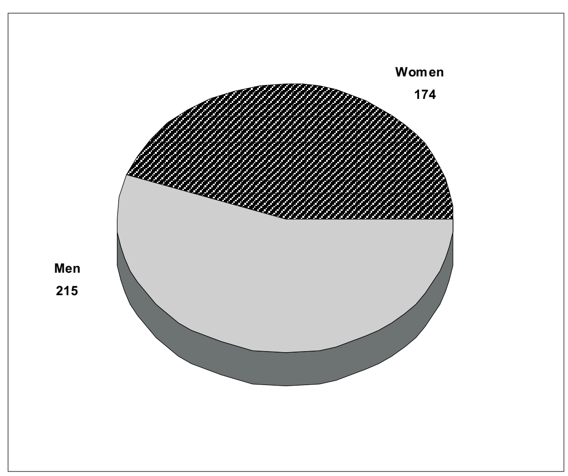

Figure 6. Total conference/workshop participants by gender.

Year 23 Educational Activities

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in international development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the year covered by this report, 35 students from 16 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 51% of these students come from countries other than the USA which shows the emphasis placed on host country institutional development (Figure 1).

INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 2001-2002, 29% of all INTSORMIL graduate participants were female. Ten of the total 35 students received full INTSORMIL scholarships. An additional 23 students received partial INTSORMIL funding and the remaining 19 students were funded from other sources as shown in Figure 3.

All 35 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding, pathology, entomology, food quality, and economics.

The number of INTSORMIL funded students has decreased gradually over the years. This is related to decreases in program budget and the loss of U. S. Principal Investigators. In 1993-1994 there were 25 U.S. PIs with the program and in 2001-2002 there are 14.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Five post doctoral scientists and 13 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during 2001-2002.

The following table is a compilation of all INTSORMIL training activities for the period July 1, 2001 through June 30, 2002.

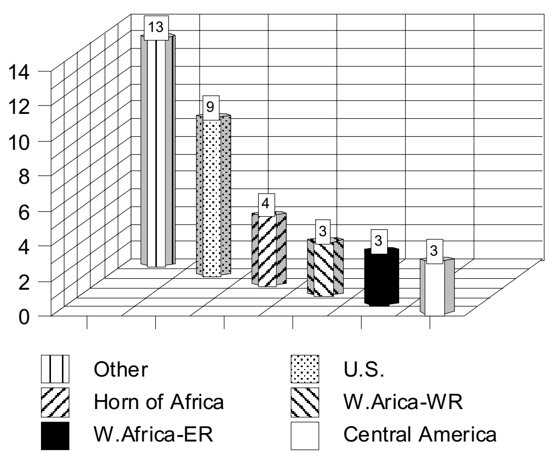

Figure 1. Degree participants by region.

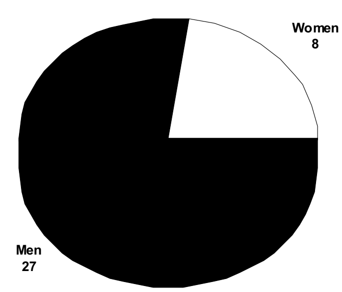

Figure 2. Degree participants by gender.

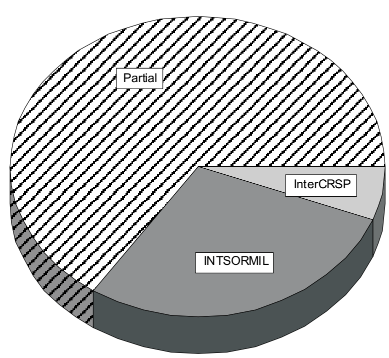

Figure 3. Degree participants source of funding.

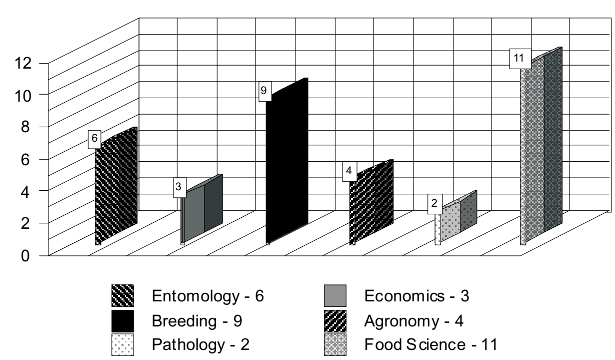

Figure 4. Degree participants discipline breakdown.

Appendices

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	All Disease and Insect Nursery
ADRA	Adventist Development and Relief Agency
AFLP	Amplified Fragment Length Polymorphisms
A.I.D	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
ANOVA	Analysis of Variance
ANPROSOR	Nicaraguan Grain Sorghum Producers Association
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARC	Agriculture Research Council, South Africa
ARGN	Anthracnose Resistant Germplasm Nursery
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ATIP	Agricultural Technology Improvement Project
BAMB	Botswana Agricultural Marketing Board
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARO	Chief Agricultural Research Officer
CARS	Central Agricultural Research Station, Kenya
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CEDA	Centro de Enseñanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro Nacional de Technoloǵia Agropecuaria y Forestal, El Salvador
CFTRI	Central Food Technological Research Institute - India

CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands, Mexico
CICP	Consortium for International Crop Protection
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnología, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre International en Recherche Agronomique pour le Développement
CITESGRAN	Centro Internacional de Tecnología de Semillas y Granos - EAP in Honduras
CLAIS	Comisión Latinoamericana de Investigadores en Sorgho
CMS	Cytoplasmic Male-Sterility System
CNIA	Centro Nacional de Investigaciones Agrícolas, Nicaragua
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CORASUR	Consolidated Agrarian Reform in the South - Belgium
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DAR	Department of Agricultural Research, Botswana
DARE	Division of Agricultural Research and Extension - Eritrea
DICTA	Dirección de Ciencia y Tecnología Agricola - Mexico
DR	Dominican Republic
DRA	Division de la Recherche Agronomique, IER Mali
DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAGA	Extended Agar Gel Assay
EAP	Escuela Agrícola Panamericana, Honduras
EARO	Ethiopian Agricultural Research Organization
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
ECARSAM	East Central Africa Regional Sorghum and Millet
ECHO	Educational Concerns for Hunger Organization

EEC	European Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
EMBRAPA-CNPMS	EMBRAPA-Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture, Honduras
EPIC	Erosion Productivity Impact Calculator
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
FEDEARROZ	Federación Nacional de Arroceros de Colombia
FENALCE	Federación Nacional de Cultivadores de Cereales
FHIA	Fundación Hondureña de Investigación Agrícola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
GWT	Uniform Nursery for Grain Mold
HIAH	Honduran Institute of Anthropology and History
HOA	Horn of Africa
HPLC	High Pressure Liquid Chromatography
HR	Hypersensitive Response
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources, University of Nebraska - Lincoln
IAR	Institute of Agricultural Research - Ethiopia
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer

ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technología Agrícolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFAD	International Fund for Agricultural Development, Rome
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IGAD	Intergovernmental Authority on Development
IHAH	Instituto Hondureño de Antropología e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agriculture
ILCA	Instituto Interamericano de Cooperación para la Agricultura
ILRI	International Livestock Research Institute - Niger
INCAP	Instituto de Nutrición de Centro America y Panama
INERA.	Institut d'Environnement et de Recherche Agricoles
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigaciónes Agrícolas, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIFAP	Instituto Nacional de Investigaciones Forestales Y Agropecuarias - Mexico
INIPA	National Agricultural Research Institute, Peru
INRAN	Institut National de Recherches Agronomiques du Niger
INTA	Instituto Nicaragüense de Tecnología Agropecuaria, Nicaragua
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronómicas, Brazil
IPIA	International Programs in Agriculture, Purdue University

IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Research Institute, Philippines
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISM	Integrated *Striga* Management
ISRA	Institute of Agricultural Research, Senegal
ISVAN	International Sorghum Anthracnose Virulence Nursery
ISVN	International Sorghum Virus Nursery
ITA	Institut de Technologie Alimentaire, Senegal
ITAT	International Tropical Adaptation Trials
ITESM	Monterrey Institute of Technology, Mexico
ITVAN	International Tall Variety Adaptation Nursery
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LASIP	Latin American Sorghum Improvement Project, Mexico
LC/MS	Liquid Chromatography/ Mass Spectrometry
LCRI	Lake Chad Research Institute
LDC	Less Developed Country
LIDA	Low Input Dryland Agriculture
LIFE	League for International Food Education
LUPE	Land Use and Productivity Enhancement
LWMP	Land and Water Management Project
MAFES	Mississippi Agricultural and Forestry Experiment Station
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MHM	Millet Head Miner
MIAC	MidAmerica International Agricultural Consortium

MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources, Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras
MSU	Mississippi State University
NAARP	Niger Applied Agricultural Research Project
NARO	National Agricultural Research Organization - Uganda
NARP	National Agricultural Research Project
NARS	National Agricultural Research System
NCRP	Niger Cereals Research Project
NGO	Non-Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory, Fort Collins, CO
NU	University of Nebraska
OAS	Organization of American States
OAU	Organization of African Unity
OFDA	Office of Foreign Disaster
OICD	Office of International Cooperation and Development
ORSTOM	L'Institut français de recherche scientifique pour le développement en coopération - France
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios
PI	Principal Investigator
PL480	Public Law No. 480
PNVA	Malien Agricultural Extension Service
PPRI/DRSS	Plant Protection Research Institute/Department of Research and Specialist Services
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains in Central America

PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Medical Research Council
PROFIT	Productive Rotations on Farms in Texas
PROMESA	Proyecto de Mejoramiento de Semilla - Nicaragua
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
QTL	Quantitative Trait Loci
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
RADRSN	Regional Advanced Disease Resistance Screening Nursery
RAPD	Random Amplified Polymorphic DNA
RARSN	Regional Anthracnose Resistance Screening Nursery
RFLP	Restriction Fragment Length Polymorphism
RFP	Request for Proposals
RI	Recombinant Inbred
RIIC	Rural Industry Innovation Centre, Botswana
ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger
ROCARS	Réseau Ouest et Centre Africain de Recherche sur le Sorgho - Mali
RPDRSN	Regional Preliminary Disease Resistance Screening Nursery
RVL	Royal Veterinary and Agricultural University, Frederiksberg, Denmark
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern Africa Development Community
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SANREM	Sustainable Agriculture and Natural Resource Management CRSP
SARI	Savannah Agricultural Research Institute - Ghana
SAT	Semi-Arid Tropics
SDM	Sorghum Downy Mildew
SDMVN	Sorghum Downy Mildew Virulent Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMIP	Sorghum and Millet Improvement Program
SMINET	Sorghum and Millet Improvement Network
SPARC	Strengthening Research Planning and Research on Commodities Project, Mali

SRCVO	Section of Food Crops Research, Mali
SRN	Secretaria de Recursos Naturales, Honduras
TAES	Texas Agricultural Experiment Station
TAMU	Texas A&M University
TARS	Tropical Agriculture Research Station
TC	Technical Committee
TPHT	Tan Plant Hybrid Trial
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UANL	Universidad Autonóma de Nuevo Leon, Mexico
UHSN	Uniform Head Smut Nursery
UNA	Universidad Nacional Agraria - Nicaragua
UNAN	Universidad Nacional Autónoma de Nicaragua UNAN-Leon - Nicaragua
UNILLANOS	Universidad Technológica de los Llanos
UNL	University of Nebraska - Lincoln
UPANIC	Union of Agricultural Producers of Nicaragua
USA	United States of America
USAID	United States Agency for International Development
USAID-RAPID	Regional Activity to Promote Integration through Dialogue and Policy Implementation
USDA	United States Department of Agriculture
USDA/TARS	United States Department of Agriculture/Tropical Agriculture Research Station
VCG	Vegetative Compatibility Group
WASAT	West African Semi-Arid Tropics
WASDON	West Africa Sorghum Desease Observation Nursery
WASIP	West Africa Sorghum Improvement Program
WCAMRN	West and Central African Millet Research Network (ROCAFREMI) - Mali
WCASRN	West and Central Africa Sorghum Research Network (ROCARS) - Mali
WSARP	Western Sudan Agricultural Research Project
WVI	World Vision International

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 2002

	Name	Where	When
1.	International Short Course in Host Plant Resistance	College Station, Texas	1979
2.	INTSORMIL PI Conference	Lincoln, Nebraska	1/80
3.	West Africa Farming Systems	West Lafayette, Indiana	5/80
4.	Sorghum Disease Short Course for Latin America	Mexico	3/81
5.	International Symposium on Sorghum Grain Quality	ICRISAT	10/81
6.	International Symposium on Food Quality	Hyderabad, India	10/81
7.	Agrimeteorology of Sorghum and Millet in the Semi-Arid Tropics	ICRISAT	1982
8.	Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82
9.	Sorghum Food Quality Workshop	El Batan, Mexico	4/82
10.	Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82
11.	Plant Pathology	CIMMYT	6/82
12.	Striga Workshop	Raleigh, North Carolina	8/82
13.	INTSORMIL PI Conference	Scottsdale, Arizona	1/83
14.	INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT	4/83
15.	Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83
16.	Stalk and Root Rots	Bellagio, Italy	11/83
17.	Sorghum in the ‘80s	ICRISAT	1984
18.	Dominican Republic/Sorghum	Santo Domingo	1984
19.	Sorghum Production Systems in Latin America	CIMMYT	1984
20.	INTSORMIL PI Conference	Scottsdale, Arizona	1/84
21.	Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santo Domingo, Dominican Republic	2/84
22.	Evaluating Sorghum for Al Toxicity in Tropical Soils of Latin America	Cali, Colombia	4/84
23.	First Consultative and Review on Sorghum Research in the Philippines	Los Banos, Philippines	6/84
24.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84
25.	International Sorghum Entomology Workshop	College Station, Texas	7/84
26.	INTSORMIL PI Conference	Lubbock, Texas	2/85
27.	Niger Prime Site Workshop	Niamey, Niger	10/85
28.	Sorghum Seed Production Workshop	CIMMYT	10/85
29.	International Millet Conference	ICRISAT	4/86
30.	Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
31.	INTSORMIL PI Conference	Kansas City, Missouri	1/87
32.	2nd Global Conference on Sorghum/Millet Diseases	Harare, Zimbabwe	3/88
33.	6th Annual CLAIS Meeting	San Salvador, El Salvador	12/88
34.	International INTSORMIL Research Conference	Scottsdale, Arizona	1/89
35.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	7/89
36.	ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
37.	Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
38	Improvement and Use of White Grain Sorghums	El Batan Mexico	12/90
39.	Sorghum for the Future Workshop	Cali, Colombia	1/91
40.	INTSORMIL PI Conference	Corpus Christi, Texas	7/91
41.	Social Science Research and the CRSPs	Lexington, KY	6/92
42.	Seminario Internacional Sobre los Cultivos de Sorgo y Maiz sus Principales Plagas y Enfermedades	Colombia	1/93
43.	Workshop on Adaptation of Plants to Soil Stresses	Lincoln, NE	8/93
44.	Latin America Workshop on Sustainable Production Systems for Acid Soils	Villavicencio, Colombia	9/93
45.	Latin America Sorghum Research Scientist Workshop (CLAIS Meeting)	Villavicencio, Colombia	9/93
46.	Disease Analysis through Genetics and Biotechnology: An International Sorghum and Millet Perspective	Bellagio, Italy	11/93
47.	INTSORMIL PI Conference	Lubbock, Texas	9/96
48.	International Conference on Genetic Improvement of Sorghum and Pearl Millet	Lubbock, Texas	9/96
49.	Global Conference on Ergot of Sorghum	Sete Lagoas MG Brazil	6/97
50.	Conference on the Status of Sorghum Ergot in North America	Corpus Christi, Texas	6/98
51.	Principal Investigators Meeting and Impact Assessment Workshop	Corpus Christi, Texas	6/98

	Name	Where	When
52.	Regional Hybrid Sorghum and Pearl Millet Seed Workshop	Niamey, Niger	9/98
53.	INTSORMIL End Use Quality Assessment Workshop	Pretoria, South Africa	12/98
54	Central America Regional Planning Workshop	Zamorano, Honduras	10/99
55.	Global 2000 Conference, Sorghum and Pearl Millet Diseases III	Guanajuato, Mexico	9/00
56.	Sorghum Research Reporting and Planning Workshop	Managua, Nicaragua	2/02

Mr. Nouri Maman, of the INTARNA Research Station, Maradi, Niger is pursuing a Ph.D. degree under the guidance of Dr. Steve Mason, Department of Agronomy, University of Nebraska, Lincoln, NE. Mr. Maman is standing in a research field of pearl millet in western Nebraska. This graduate degree program demonstrates the win-win benefits of degree training in the INTSORMIL program. Pearl millet is a traditional crop in Niger. It is a new crop with potential for adaptation to the dryland areas of western Nebraska. Mr. Maman's graduate studies in Nebraska are a unique opportunity for an international student to become acquainted with farming systems in the U.S. and to share the benefits of his experience with researchers and farmers in the U.S. Upon completion of his Ph.D., Mr. Maman will use the research skills obtained during graduate study to improve pearl millet research addressing Nigerian production problems.